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[TITLE OF THE INVENTION] FOCUSING AND TILTING ADJUSTMENT SYSTEM FOR LITHOGRAPHY ALIGNER, MANUFACTURING APPARATUS OR INSPECTION APPARATUS

[CLAIMS]

[Claim 1] A scanning exposure apparatus characterized by comprising:

(a) an imaging system for projecting an image of a pattern of a mask onto a substrate at an imaging field;

(b) a scanning mechanism for moving the mask and the substrate in a scanning direction relative to the imaging system;

(c) an adjusting system for adjusting a focus of the image which is projected on the substrate;

(d) a first detection system having a detection area at a first position located outside the imaging field of the imaging system and spaced apart from the imaging field in the scanning direction, the first detection system detecting a position of a surface of the substrate in a Z-direction;

the scanning exposure apparatus further comprising:

(e) a second detection system having a detection area at a second position located outside the imaging field of the imaging system and spaced apart from the first position in a direction intersecting the scanning direction, the second detection system detecting the position of the surface of the substrate in the Z-direction;

the scanning exposure apparatus further comprising:

(f) a third detection system having a detection area at a third position located outside the imaging field of the imaging system, spaced apart from the imaging field in a direction intersecting the scanning direction and spaced apart from the second position in the scanning direction, the third detection system detecting the position of the surface of the substrate in the Z-direction; and

the scanning exposure apparatus further comprising:

(g) a calculator connected to the first and second detection systems and calculating a deviation between the first Z-position detected by the first detection system and a target Z-position and storing the second Z-position detected by the second detection system at the time of detection by the first detection system; and

(h) a controller connected to the adjusting system and to the calculator and to the third detection system and controlling the adjusting system on the basis of the calculated deviation, the stored second Z-position and the third Z-position detected by the third detection system when the area on the substrate corresponding to the detection area of the first detection system is positioned in the imaging field of the imaging system by movement of the scanning mechanism.

[Claim 2] The scanning exposure apparatus according to claim 1, characterized in that the scanning mechanism includes a mask stage for holding the mask, a substrate stage for holding the substrate, and a

synchronizing drive system for moving the mask stage and the substrate stage at a speed ratio corresponding to a projection magnification of the imaging system.

[Claim 3] The scanning exposure apparatus according to claim 2, characterized in that the substrate stage includes an attraction portion for attracting a back surface of the substrate, and an auxiliary plate portion surrounding the substrate at a height approximately equal to the surface of the substrate when the substrate is supported on the attraction portion.

[Claim 4] The scanning exposure apparatus according to claim 3, characterized in that the second detection system and the third detection system are arranged to detect a position of a surface of the auxiliary plate portion in the Z-direction by at least one of the detection areas when a shot area of the substrate to be exposed by the pattern of the mask is at a peripheral portion of the substrate.

[Claim 5] The scanning exposure apparatus according to claim 4, characterized in that the first detection system generates one of a Z-direction positional error value of the surface of the substrate relative to a predetermined reference Z-position with respect to the first detection system and a Z-direction positional error value of the auxiliary plate portion relative to the predetermined reference Z-position with respect to the first detection system;

the second detection system generates one of a Z-direction positional error value of the surface of the substrate relative to a predetermined reference Z-position with respect to the second detection system and a Z-direction positional error value of the auxiliary plate portion relative to the predetermined reference Z-position with respect to the second detection system; and

the third detection system generates one of a Z-direction positional error value of the surface of the substrate relative to a predetermined reference Z-position with respect to the third detection system and Z-direction positional error value of the auxiliary plate portion relative to the predetermined reference Z-position with respect to the third detection system.

[Claim 6] The scanning exposure apparatus according to claim 5, characterized in that in a case that the predetermined reference Z-positions with respect to the first, second and third detection systems differ from each other, the differences between the predetermined reference Z-positions are detected by a calibration.

[Claim 7] The scanning exposure apparatus according to claim 4, characterized in that in a case that the scanning direction of the substrate is a Y-direction and that a direction perpendicular to each of the Y-direction and the Z-direction is an X-direction, the first detection system includes a first multi-point type focus detector having a plurality of detection areas which are

aligned in a row along the X-direction on the substrate over a range of a size of the imaging field of the imaging system in the X-direction.

[Claim 8] The scanning exposure apparatus according to claim 7, characterized in that the second detection system includes a plurality of second focus detectors having detection areas on both sides of the row of the plurality of detection areas of the first multi-point focus detector in the X-direction, each of the second focus detectors separately detecting the Z-direction position of the surface of one of the substrate and the auxiliary plate portion at each of the detection areas.

[Claim 9] The scanning exposure apparatus according to claim 8, characterized in that the third detection system includes a plurality of third focus detectors on both sides of the imaging field of the projection system in the X-direction, each of the third focus detectors separately detecting the Z-direction position of the surface of one of the substrate and the auxiliary plate portion at each of the detection areas.

[Claim 10] A projection exposure apparatus characterized by comprising:

(a) an imaging system for projecting an image of a mask pattern onto a substrate at a projection field;

(b) a movable stage mechanism movable in a direction which intersects X and Y directions to position the substrate with respect to the projected image of the mask

pattern;

(c) an adjusting mechanism for adjusting a focus of the image of the mask pattern which is projected on the substrate;

(d) a first detection system having a detection area at a first position located outside the projection field of the imaging system and spaced apart from the projection field in the Y direction, the first detection system detecting a position of a surface of the substrate in a Z direction;

the projection exposure apparatus further comprising:

(e) a second detection system having a detection area at a second position located outside the projection field of the imaging system and spaced apart from the first position in the X direction, the second detection system detecting the position of the surface of the substrate in the Z direction;

the projection exposure apparatus further comprising:

(f) a third detection system having a detection area at a third position located outside the projection field of the imaging system, spaced apart from the projection field in the X direction and spaced apart from the second position in the Y direction, the third detection system detecting the position of the surface of the substrate in the Z direction;

the projection exposure apparatus further comprising:

(g) a calculator connected to the first and second

detection systems, and calculating a deviation between the first Z-position detected by the first detection system and a target Z-position and for storing the second Z-position detected by the second detection system at the time of detection made by the first detection system; and

(h) a controller connected to the adjusting mechanism and the calculator and the third detection system, and controlling the adjusting mechanism on the basis of the calculated deviation, the stored second Z-position and the third Z-position detected by the third detection system when the area on the substrate corresponding to the detection area of the first detection system is positioned in the projection field of the imaging system by the movable stage mechanism.

[Claim 11] The projection exposure apparatus according to claim 10, characterized in that the first detection system includes a plurality of first focus detectors having a plurality of detection areas which are aligned in a row along the X direction in a range according to a size of the projection field of the imaging system in the X direction, each of the first focus detectors separately detecting the Z-position of the surface of the substrate at each of the detection areas.

[Claim 12] The projection exposure apparatus according to claim 11, characterized in that the second detection system includes two second focus detectors having two detection areas placed on both sides of the row of the

plurality of detection areas of the first detection system, each of the second focus detectors separately detecting the Z-position of the surface of the substrate at each of the two detection areas.

[Claim 13] The projection exposure apparatus according to claim 12, characterized in that the third detection system includes two third focus detectors placed on both sides of the projection field of the imaging system in the X direction, each of the third focus detectors separately detecting the Z-position of the surface of the substrate at each of the two detection areas.

[Claim 14] The projection exposure apparatus according to claim 13, characterized in that the movable stage mechanism includes a mount portion for attracting a back surface of the substrate and an auxiliary plate portion which surrounds the substrate at a height substantially equal to the surface of the substrate when the substrate is supported on the mount portion, a surface of the auxiliary plate being detected by one of the two second focus detectors and one of the two third focus detectors.

[Claim 15] A scanning exposure method for transferring a pattern of a mask onto a sensitive substrate by projecting a part of the pattern of the mask on the sensitive substrate through a projection system and by moving the mask and the sensitive substrate relative to a projection field of the projection system, the method

characterized by comprising the steps of:

(a) mounting the sensitive substrate on a holder having an auxiliary plate portion surrounding the sensitive substrate at a height substantially equal to a height of a surface of the sensitive substrate;

(b) reading a focus error of an exposure area of the sensitive substrate onto which a part of the pattern of the mask is to be projected, the focus error of the exposure area being read before the exposure area reaches the projection field of the projection system during scanning movement of the holder and the sensitive substrate;

the scanning exposure method further comprising the steps of :

(c) detecting a focus error of a part of the surface of one of the sensitive substrate and the auxiliary plate portion by an exposure position focus detection system disposed apart from the projection field of the projection system in a direction perpendicular to a direction of the scanning movement when the exposure area on the sensitive substrate reaches the projection field; and

(d) adjusting a focus between the projection system and the sensitive substrate on the basis of the focus errors detected by the steps (b) and (c) so that the focus error of the exposure area on the sensitive substrate is corrected in the projection field of the projection system.

[Claim 16] The scanning exposure method according to claim 15, characterized in that the method is applied to

a projection aligner having a projection system having an effective working distance to the surface of the substrate of 20 mm or less.

[Claim 17] The scanning exposure method according to claim 15, characterized in that the method is applied to an immersion projection exposure apparatus, wherein a liquid is filled in a space which contains a projection optical path and which is located between the sensitive substrate and a transparent optical element disposed at an image plane side of the projection optical system.

[Claim 18] The scanning exposure method according to claim 17, characterized in that the projection optical system has a working distance such that a thickness of the liquid between the sensitive substrate and the transparent optical element of the projection optical system is 2 mm or less.

[Claim 19] The scanning exposure method according to claim 15, characterized in that the method is applied to a scanning exposure apparatus having a catadioptric projection system which has a refractive optical element and a reflecting optical element;

wherein in the scanning exposure apparatus, a transparent optical element is disposed at an image plane side.

[Claim 20] The scanning exposure method according to claim 19, characterized in that the transparent optical element disposed at the image plane side is a prism mirror

having an emergent surface substantially parallel to the surface of the sensitive substrate.

[Claim 21] A focusing apparatus which is provided in an apparatus having an objective optical system to enable control focusing between a surface of a workpiece and the objective optical system, the focusing apparatus characterized by comprising:

(a) a first detection system having a detection area at a first position located outside a field of the objective optical system, the first detection system detecting a position of the surface of the workpiece in a direction of the focusing;

the focusing apparatus further comprising:

(b) a second detection system having a detection area at a second position located outside the field of the objective optical system and spaced apart from the first position, the second detection system detecting the position of the surface of the workpiece in the direction of the focusing;

the focusing apparatus further comprising:

(c) a third detection system having a detection area at a third position located outside the field of the objective optical system and spaced apart from each of the first and second positions, the third detection system detecting the position of the surface of the workpiece in the direction of the focusing;

the focusing apparatus further comprising:

(d) a calculator connected to the first and second detection systems, and calculating a deviation between the first focus position detected by the first detection system and a target focus position and for storing the second focus position detected by the second detection system at the time of detection made by the first detection system; and

(e) a controller connected to the calculator and to the third detection system, and controlling focusing of the objective optical system on the surface of the workpiece, on the basis of the calculated deviation, the stored second focus position and the third focus position detected by the third detection system, when the area on the workpiece corresponding to the detection area of the first detection system is positioned in the field of the objective optical system by relative movement of the workpiece and the objective optical system.

[Claim 22] A method of controlling focusing of an objective optical system on a surface of a workpiece when the workpiece and a field of the objective optical system are moved relative to each other in X and Y directions, the method characterized by comprising the steps of:

(a) mounting the workpiece on a holder having an auxiliary plate portion which surrounds the workpiece at a height substantially equal to a height of the surface of the workpiece;

(b) reading a focus error of a predetermined local

portion of the surface of the workpiece before the local portion of the workpiece reaches the field of the objective optical system during movement of the holder and the workpiece in a predetermined moving direction;

the method further comprising the steps of:

(c) detecting a focus error of a part of the surface of one of the workpiece and the auxiliary plate portion by a first focus detection system, which is disposed apart from the field of the objective optical system in a direction perpendicular to the moving direction, when the local portion of the workpiece reaches the field; and

(d) controlling the focusing between the objective optical system and the workpiece on the basis of the focus errors detected by the steps (b) and (c) so that the focus error of the local portion of the workpiece is corrected in the field of the objective optical system.

[Claim 23] The method according to claim 22, characterized in that the method is applied to at least one of a manufacturing instrument, a lithography exposure apparatus, a writing apparatus and an inspection apparatus having a small effective working distance such that a detecting beam of an oblique incident light type focus detector is prevented from being obliquely led to the surface of the workpiece immediately below the objective optical system.

[Claim 24] A projection exposure apparatus for transferring an image of a mask pattern onto a sensitive

substrate via an optical imaging system and a liquid in a space between the optical imaging system and the sensitive substrate, the projection exposure apparatus characterized by comprising:

an assembly which holds a plurality of optical elements of the optical imaging system, at least an end portion of the assembly being immersed in the liquid;

the projection exposure apparatus further comprising:

an end optical element which is attached to the end portion of the assembly and which has an end surface contacting with the liquid;

wherein the end surface of the end optical element and a surface of the end portion of the assembly are planes which are substantially flush with each other so as to prevent flow of the liquid from being obstructed.

[Claim 25] A method adopting a projection system and processing a formation pattern in a semiconductor wafer, the method characterized by comprising:

(a) attaching step of attaching the semiconductor wafer to a holder, the holder including a periphery portion and a wall portion which is arranged vertically in the periphery portion, enabling formation of a liquid layer on the wafer to provide a liquid immersion state between a surface of the wafer and the projection system;

the method further comprising:

(b) scanning step of scanning the holder along an image plane of the projection system so as to perform

scanning exposure by projecting an image of the formation pattern onto the wafer via the projection system and the liquid layer; and

(c) correction step of correcting at least one of a focusing error between the surface of the wafer and an image plane of the projection system and a tilting error between the surface of the wafer and the image plane of the projection system, by using a focus detection system during the scanning step;

wherein the focus detection system has a plurality of focus detection points arranged outside of the image plane of the projection system.

[Claim 26] The method according to claim 25, characterized in that the projection system has a resolution which is less than 0.5 micrometers.

[Claim 27] A scanning exposure method for transferring a pattern of a mask onto a substrate via an imaging system, characterized by comprising:

a step of providing a first detection system having a first detection area located outside an imaging field of the imaging system and spaced apart from the imaging field in a scanning direction, the first detection system detecting a position of a surface of the substrate in a direction of an optical axis of the imaging system;

the scanning exposure method further comprising:

a step of providing a second detection system having a second detection area located outside the imaging field of

the imaging system and spaced apart from the first detection area in a direction intersecting the scanning direction, the second detection system detecting the position of the surface of the substrate in the direction of the optical axis;

the scanning exposure method further comprising:

a step of providing a third detection system having a third detection area located outside the imaging field of the imaging system and spaced apart from the imaging field in the direction intersecting the scanning direction and spaced apart from the second area in the scanning direction, the third detection system detecting a deviation between a target position and the position of the surface of the substrate in the direction of the optical axis;

the scanning exposure method further comprising:

a step of determining a target position of the third detection system, on the basis of detection results by the first and second detection systems, during the exposure of the substrate; and

a step of adjusting a positional relationship between the surface of the substrate and the image plane of the imaging system, based on the detection results by the first and second detecting systems and a detection result by the third detection system, during the exposure of the substrate.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[TECHNICAL FIELD TO WHICH THE INVENTION BELONGS]

The present invention relates to semiconductor fabrication and more particularly to a lithography exposure apparatus (aligner) for transferring a circuit pattern from a mask or a reticle onto a sensitive substrate.

[0002] The present invention also relates to a system for detecting a focal point on a workpiece (wafer, substrate or plate etc.) and for detecting a tilt of the workpiece, which is applicable to certain kinds of apparatus such as an apparatus for manufacturing a workpiece or imaging a desired pattern in a surface of a workpiece using a laser or electron beam and an apparatus for optically inspecting the state of a surface of a workpiece.

[0003]

[CONVENTIONAL ART]

Recently, dynamic random access memory semiconductor chips (DRAMs) having an integration density of 64 Mbits have been mass-produced by semiconductor fabrication techniques. Such chips are manufactured by exposing a semiconductor wafer to images of circuit patterns to form e.g. ten or more layers of circuit patterns in a superposition manner.

[0004] Presently, lithography apparatuses used for such chip fabrication are projection aligners in which a circuit

pattern drawn in a chromium layer on a reticle (mask plate) is transferred onto a resist layer on a wafer surface through a 1/4 or 1/5 reduction optical imaging system (namely, reduction projection optical system) by irradiating the reticle with i-line radiation (wavelength: 365 nm) of a mercury discharge lamp or pulse light having a wavelength of 248 nm from a KrF excimer laser.

[0005] Projection exposure apparatuses (projection aligners) used for this purpose are generally grouped, according to the types of imaging optical system, into those using a step-and-repeat system (i.e., so-called steppers) and those using a step-and-scan system which has attracted attention in recent years.

[0006] In the step-and-repeat system, a process is repeated in which, each time a wafer is moved to a certain extent in a stepping manner, a pattern image on a reticle is projected on a part of the wafer by using a reduction projection lens system. The reduction projection system is formed only of a refractive optical material (lens element) and having a circular image field or a unit magnification projection lens system formed of a refractive optical material (lens element), a prism mirror and a concave mirror and having a noncircular image field. By the image field, a shot area on the wafer or plate is exposed to or with the pattern image.

[0007] In the step-and-scan system, a wafer is exposed to (with) an image of a portion of a circuit pattern on a

reticle (for example, a reticle in the form of a circular-arc slit). The portion of the circuit pattern of the recitle is projected on the wafer through a projection optical system. Simultaneously, the reticle and the wafer are continuously moved at constant speeds at a speed ratio according to the projection magnification, thus exposing one shot area on the wafer to the image of the entire circuit pattern on the reticle in a scanning manner.

[0008] For example, as described on pp 256 to 269 of SPIE Vol. 922 Optical/Laser Microlithography (1988), the step-and-scan system is arranged (constructed) so that, after one shot area on the wafer has been scanned and exposed, the wafer is moved one step for exposure of an adjacent shot area, and so that the effective image field of the projection optical system is limited to a circular-arc slit. Also, the projection optical system is considered to be a combination of a plurality of refractive optical elements and a plurality of reflecting optical elements, such as one disclosed in U.S. Patent No. 4,747,678 (to Shafer).

[0009] U.S. Patent to Nishi discloses an example of an aligner in which a step-and-scan system is realized by mounting a stepper reduction projection lens having a circular image field. This publication also discloses a method in which a pattern image projected at the time of scanning exposure is transferred onto a wafer by increasing the depth of focus (DOF) by a predetermined amount on the

wafer.

[0010] In the field of lithography technology, it is now desirable to be able to fabricate semiconductor memory chips having an integration density and fineness of the 1 or 4 Gbit class by light exposure. Since light exposure techniques have a long technological history and are based on a large amount of accumulated know-how, it is convenient to continue use of light exposure techniques. It is also advantageous to use light exposure techniques considering drawbacks of alternative electron beam exposure or X-ray technologies.

[0011] It is believed that resolutions in terms of minimum line width (feature width) of about 0.18 μm and 0.13 μm are required with respect to 1 Gbit and 4 Gbit memory chips, respectively. To achieve resolution of such a line width, far ultraviolet rays having a wavelength of 200 nm or shorter, e.g., those produced by an ArF excimer laser, are used for illumination for irradiating the reticle pattern.

[0012] As optical vitreous materials having a suitable transmittance with respect to far ultraviolet rays (having a wave-length of 400 nm or shorter), quartz (SiO_2), fluorite CaF_2, lithium fluoride (LiF_2), magnesium fluoride (MgF_2) and so on are generally known. Quartz and fluorite are optical vitreous materials necessary for forming a projection optical system having high resolution in the range of far ultraviolet rays.

[0013] However, it is necessary to consider the fact that, if the numerical aperture (NA) of a projection optical system is increased to attain high resolution while the field size is increased, the diameter of lens elements made of quartz or fluorite becomes so large that it is consequently difficult to manufacture such lens elements.

[0014] Also, if the numerical aperture (NA) of the projection optical system is increased, the depth of focus (DOF) ΔF is inevitably reduced. In general, the depth of focus ΔF is defined by wavelength, numerical aperture NA, a process coefficient Kf ($0<Kf<1$) as shown below if the Rayleigh's theory of imaging formation is applied:

[0015]

$$\Delta F = Kf\cdot(\lambda/NA^2)$$

Accordingly, the depth of focus ΔF in the atmosphere (air) is about 0.240 µm if the wavelength is 193 nm, that is, equal to that of ArF excimer laser light, the numerical aperture NA is set to about 0.75 and the process coefficient Kf is 0.7. In this case, the theoretical resolution (minimum line width) ΔR is expressed by the following equation using process coefficient Kr ($0<Kr<1$):

[0016]

$$\Delta R = Kr\cdot(\lambda/NA)$$

Accordingly, under the above-mentioned conditions, the resolution ΔR is about 0.154 µm if the process coefficient

Kr is 0.6.

[0017] As described above, while it is necessary to increase the numerical aperture of the projection optical system in order to improve the resolution, it is important to notice that the depth of focus decreases abruptly if the numerical aperture is increased. If the depth of focus is small, there is a need to improve the accuracy, reproducibility (reproducing accuracy) and stability with which an automatic focusing system for coincidence between the best imaging plane of the projection optical system and the resist layer surface on the wafer is controlled.

[0018] On the other hand, considering the projection optical system from the standpoint of design and manufacturing, a configuration is possible in which the numerical aperture is increased without increasing the field size. However, if the numerical aperture is set to a substantially large value, the diameter of lens elements is so large that it is thus difficult to form and work the optical vitreous material (e.g. quartz and fluorite).

[0019] Then, as a means for improving the resolution without largely increasing the numerical aperture of the projection optical system, an immersion projection method may be used in which the space between the wafer and the projection optical system is filled with a liquid, see U.S. Pat. No. 4,346,164 (to Tabarelli).

[0020] In this immersion projection method, a space between the wafer and the optical element constituting the

projection optical system on the projection end side (image plane side) is filled with a liquid having a refractive index close to the refractive index of the photoresist layer, to increase the effective numerical aperture of the projection optical system seen from the wafer side, i.e. improving the resolution. This immersion projection method is expected to attain good imaging performance by selecting the liquid used.

[0021] Projection aligners as presently known generally are provided with an automatic focusing (AF) system. The automatic focusing (AF) system is capable of precisely controlling the relative positions of the wafer and the projection optical system so that the wafer surface coincides with the optimum imaging plane (reticle conjugate plane) of the projection optical system. This AF system includes a surface position detection sensor for detecting a change in the height position (Z-direction position) of the wafer surface in a non-contact manner, and a Z-adjustment mechanism for adjusting the spacing between the projection optical system and the wafer on the basis of the detected change.

[0022] Also in projection aligners presently used, an optical type or air micrometer type sensor is used as the surface position detection sensor, and a holder (and a Z-stage) for supporting the wafer, provided as the Z-adjustment mechanism. The holder (and the Z- stage) for supporting the wafer is moved vertically to sub-micron

accuracy.

[0023] If such an AF system is provided in an aligner to which the immersion projection method is applied, it is natural that an air micrometer type sensor cannot be used and an optical sensor is exclusively used since the wafer is held in a liquid. In such a case, an optical focus sensor, such as one disclosed in U.S. Pat. No. 4,650,983 (to Suwa), for example, is constructed so that a measuring beam (an imaging beam of a slit image) is obliquely projected into the projection field on the wafer and so that the beam reflected by the wafer surface is received by a photoelectric detector through a light receiving slit. The change in the height position of the wafer surface, i.e., the amount of focus error, is detected from a change in the position of the reflected beam occurring at the light receiving slit.

[0024] If an oblique incident light type focus sensor such as the one disclosed in U.S. Pat. No. 4,650,983 is directly mounted in a projection aligner in which the conventional projection optical system having a working distance of 10 to 20 mm is immersed in a liquid, a problem described below arises. In such a case, it is necessary to set, in the liquid, the following optical system via or through which the projected beam and the reflected beam pass. Namely, the projected beam is emitted from a projecting objective lens of the focus sensor to reach the projection field of the projection optical system on the

wafer; and the reflected beam is reflected by the wafer to reach a light receiving objective lens.

[0025] Therefore, the beam of the focus sensor travels through a long distance in the liquid, so that unless the temperature distribution in the liquid is stabilized with high accuracy, the projected beam and the received beam fluctuate by a change in refractive index due to a temperature nonuniformity, resulting in deterioration in the accuracy of focus detection (i.e. detection of the height position of the wafer surface).

[0026] Moreover, to achieve a resolution of 0.15 λm or less by the immersion projection method, it is necessary to set the working distance of the projection optical system to a sufficiently small value, as mentioned above. Therefore, oblique projection itself of the projected beam of the oblique incident light type focus sensor from the space between the projection optical system and the wafer toward the projection area on the wafer becomes difficult to perform. For this reason, one important question arises as to how an automatic focusing system applicable to the immersion projection method is arranged or constructed.

[0027] On the other hand, aligners (exposure apparatus) having an unit magnification type (hereinafter described as "1X") projection optical systems are being used in the field of manufacturing liquid crystal display devices (flat panel displays) as well as in the field of manufacturing semiconductor devices. Recently, for this kind of aligner,

a system has been proposed in which a plurality of 1X projection optical systems of a certain type are arranged and in which a mask and a photosensitive plate are moved integrally with each other for scanning. It is desirable that, ideally, the working distance of the 1X projection optical systems used is extremely small. Each 1X projection optical system is of a single Dyson type such as that disclosed in U.S. Pat. No. 4,391,494 (to Hershel) or a double Dyson type such as that disclosed in U.S. Pat. No. 5,298,939 (to Swanson et al.).

[0028] In an aligner having such a Dyson type projection optical system, the working distance (i.e. spacing between the exit surface of a prism mirror and the image plane) can be sufficiently reduced to limit various aberrations or distortions of the projected image to such small values that there is practically no problem due to the aberrations or distortions. In this kind of aligner, therefore, a detection area on the photosensitive substrate, of which focus is detected by the focus sensor (e.g., the irradiation position of the projected beam in the oblique incident light system or the air-exhaust position in the air micrometer system), is ordinarily set to a position deviating or shifting from the effective projection field region of the projection optical system, that is, set in an off-axis manner.

[0029]

[PROBLEM TO BE SOLVED BY THE INVENTION]

For this reason, it is impossible to actually detect whether the area of the substrate which is exposed to projected light from a circuit pattern is precisely adjusted in a best focus state or condition.

[0030] Also in apparatuses for writing a pattern on a substrate or in apparatuses which perform processing (or manufacturing) by using a spot of a laser beam or an electron beam, the working distance between the substrate and the objective lens system (or an electronic lens system) for projecting the beam becomes so small. As a result, there is a possibility that an AF sensor capable of detecting a focusing error of the processing position or the drawing position on the substrate surface in the field of the objective optical system cannot be mounted.

[0031] In such a case, the detection point of the AF sensor is only placed outside the field of the objective lens system to detect a focusing error, and it thus is not possible to detect whether a focusing error occurs actually at the processing position or writing position in the field of the objective lens system.

[0032] The same can also be said with respect to an apparatus for optically inspecting a pattern drawn on a reticle or mask with photolithography or a fine pattern formed on a wafer. That is, this is because this kind of inspection apparatus is also provided with an objective lens system for inspection; and because the end of the objective lens system faces a surface of an specimen (a

plate) to be inspected while being spaced apart from the surface of the specimen by a predetermined working distance.

[0033] Thus, if an objective lens system having a comparatively large magnifying power and high resolution is used, the working distance is so small that the same problem relating to the disposition or characteristic of the AF sensor is encountered.

[0034]

[MEANS FOR SOLVING THE PROBLEM]

In view of the above-described problems of the related art, the present invention provides a projection aligner (exposure apparatus) and an exposure method which enable high-precision focusing control and high- precision tilt control even if a projection optical system reducing the working distance in comparison with the conventional projection optical system is incorporated.

[0035] The invention is directed to a step-and-repeat aligner in which a surface of a sensitive substrate is exposed to a pattern image projected through an projection system or a scanning exposure apparatus (scanning aligner) in which a mask (or a reticle) and a sensitive substrate are moved relative to an imaging system while a pattern image is being projected, and relative to a system suitable for detecting a focal point and a tilt in these kinds of exposure apparatus (aligners).

[0036] In the exposure apparatus and method of the

present invention, focusing control and tilt control are performed with respect to a shot area at a peripheral position on a sensitive substrate.

[0037] The scanning exposure apparatus and scanning exposure method of the present invention enable high-precision focusing control and high- precision tilt control with respect to an exposed area (exposure area) of a sensitive substrate, without setting a focus detection area in the projection field of a projection optical system.

[0038] The focus sensor and focus detection method of the present invention stably detect an error in focusing or tilting of a surface of a sensitive substrate immersed in a liquid in an immersion type projection aligner or immersion type scanning aligner designed to improve the depth of focus. The focus sensor and focus detection method of the present invention are suitable for a manufacturing (processing) apparatus, a drawing apparatus or an inspection apparatus having an objective optical system of a small working distance.

[0039] The present invention is applicable to a scanning exposure apparatus having an imaging system (a projection lens system) for projecting an image of a pattern of a mask (a reticle) on a substrate (a wafer) through an imaging field, a scanning mechanism (a reticle stage or wafer XY stage) for moving the mask and the substrate in a scanning direction relative to the imaging system, and a Z-drive system for driving the substrate and the imaging system

relative to each other in a Z-direction to focus the projected image; the present invention is also applicable to a projection aligner (i.e., stepper) having an imaging system for projecting an image of a pattern of a mask on a substrate through a projection field, a movable stage mechanism which moves in X and Y directions in order to position the substrate with respect to the image of the pattern to be projected, and a Z-drive mechanism for driving the substrate and the imaging system relative to each other in a Z-direction to focus the image to be projected.

[0040] The scanning mechanism or the movable stage mechanism of the exposure apparatus or aligner may be a mechanism for horizontally maintaining a mask or substrate. Alternatively, it may be a mechanism for maintaining a mask or substrate at a certain angle from a horizontal plane, for example, a vertical stage mechanism for moving a mask or substrate in a horizontal or vertical direction while maintaining the mask or substrate in a vertical attitude. In this case, a plane along which the mask or substrate is moved corresponds to X- and Y-directions; and Z-direction, perpendicular to each of X- and Y-directions, is also referred to (for example, in correspondence with the direction of the optical axis of a laterally-arranged projection optical system or the direction of principal rays).

[0041] According to the present invention, the aligner

is provided with a first detection system, a second detection system and a third detection system. The first detection system has a detection area at a first position located outside the imaging field of the imaging system and spaced apart from the same in the scanning direction (Y-direction), the first detection system detecting the position of an obverse (upper) surface of the substrate in the Z-direction; the second detection system has a detection area at a second position located outside the imaging field of the imaging system and spaced apart from the first position in a direction (X) which is perpendicular to the scanning direction (Y), the second detection system detecting the position of the surface of the substrate in the Z-direction; and the third detection system has a detection area at a third position located outside the imaging field of the imaging system, spaced apart from the same in a direction (X) perpendicular to the scanning direction (Y) and also spaced apart from the second position in the scanning direction (Y), and the third detection system detects the position of the surface of the substrate in the Z-direction.

[0042] According to the present invention, the aligner is further provided with a calculator for calculating a deviation between the first Z-position detected by the first detection system and a target Z- position, and for temporarily storing the second Z-position detected by the second detection system at the time of detection made by

the first detection system; and a controller for controlling the Z-drive system on the basis of the calculated deviation, the stored second Z-position and the third Z-position detected by the third detection system when the area on the substrate corresponding to the detection area of the first detection system is positioned in the imaging field of the imaging system by a movement caused by the scanning mechanism or the movable stage mechanism.

[0043] The present invention is applicable to a scanning exposure method in which all of a pattern of a mask (a reticle) is transferred onto a sensitive substrate (a wafer) by projecting a part of the mask pattern on the sensitive substrate through a projection optical system and by simultaneously moving the mask and the sensitive substrate relative to a projection field of the projection optical system.

[0044] The method of the present invention includes a step of mounting the sensitive substrate on a holder having an auxiliary plate portion formed so as to surround the sensitive substrate at a height substantially equal to the height of a surface of the sensitive substrate; and a step of previously reading a focus error of an exposure area on the sensitive substrate; wherein a part of the pattern of the mask is to be projected on an area of the sensitive substrate, and the focus error of the exposure area being read before the exposure area reaches the projection field

of the projection optical system during scanning movement of the holder and the sensitive substrate. The method of the present invention further includes a step of detecting a focus error of a part of the surface of the sensitive substrate or the auxiliary plate portion by an exposure position focus detection system disposed apart from the projection field of the projection optical system in a direction (X) perpendicular to the direction (Y) of the scanning movement when the exposure area on the sensitive substrate reaches the projection field; and a step of adjusting the distance between the projection optical system and the sensitive substrate on the basis of the detected focus error so that the focus error of the exposure area on the sensitive substrate is corrected in the projection field of the projection optical system.

[0045] A focus detection sensor or a focus detection method suitable for manufacturing (processing) apparatuses, imaging apparatuses and inspection apparatuses is achieved similarly by replacing the projecting optical system, used for the above-described exposure apparatus (aligner) or the exposure method, with an objective optical system for manufacturing writing, imaging or inspection.

[0046]

[EMBODIMENT OF THE INVENTION]

FIG. 1 shows the entire construction of a projection exposure apparatus in a first embodiment of the present invention. The projection exposure apparatus in the first

embodiment is a lens-scan type projection aligner in which a circuit pattern on a reticle is projected onto a semiconductor wafer through a reduction projection lens system having circular image fields telecentrically formed on the object side and the image side while the reticle and the wafer are being moved relative to the projection lens system to be scanned.

[0047] An illumination system shown in FIG. 1 includes an ArF excimer laser light source for emitting pulse light having a wavelength of 193 nm, a beam expander for shaping a cross section of the pulse light from the light source into a predetermined shape, an optical integrator such as a fly's-eye lens for forming a secondary light source image (a set of a plurality of point light sources) by receiving the shaped pulse light, a condenser lens system for condensing the pulse light from the secondary light source image into pulse illumination light having a uniform illuminance distribution, a reticle blind (illumination field stop) for shaping the pulse illumination light into a rectangular shape elongated in a direction perpendicular to the scanning direction at the time of scanning exposure, and a relay optical system for imaging the rectangular opening of the reticle blind on a reticle R in cooperation with a mirror 11 and a condenser lens system 12 shown in FIG. 1.

[0048] The reticle R is supported on a reticle stage 14 by vacuum suction attraction. The reticle stage 14 can

move at a constant speed in one dimension with a large stroke during scanning exposure. The reticle stage 14 is guided on a column structure 13 of an aligner body laterally as viewed in FIG. 1 to move for scanning. The reticle stage 14 is also guided so as to move in a direction perpendicular to the plane of the figure.

[0049] The coordinate position and the fine rotational deviation of the reticle stage 14 in an XY-plane are successively measured by a laser interferometer system (IFM) 17. The laser interferometer system 17 projects a laser beam onto a moving mirror (plane mirror or corner mirror) 16 attached to a portion of the reticle stage 14; and the laser interferometer system 17 receives the laser beam reflected by the mirror 16 (namely, performs light-reception). A reticle stage controller 20 controls a motor 15 (such as a linear motor or a voice coil) for driving the reticle stage 14 on the basis of the XY-coordinate position measured by the interferometer system 17, thereby controlling the scanning movement and the stepping movement of the reticle stage 14.

[0050] When a part of a circuit pattern area on the reticle R is irradiated with rectangular shaped pulse of light emitted from the condenser lens system 12, an imaging light beam from the pattern in the illuminated part is projected and imaged on a sensitive resist layer applied on the upper (i.e. principal) surface of a wafer W through a 1/4 reduction 1/4 reduction projection lens system PL. The

optical axis AX of the 1/4 reduction projection lens system PL is placed so as to extend through center points of the circular image fields and to be coaxial with the optical axes of the illumination system 10 and the condenser lens system 12.

[0051] The 1/4 reduction projection lens system PL includes a plurality of lens elements. The 1/4 reduction projection lens system is made e.g. of two different materials, such as quartz and fluorite having high transmittance with respect to ultra- violet rays having a wavelength of 193 nm. Fluorite is used mainly to form lens elements having a positive power. The air in the lens barrel in which the lens elements of the 1/4 reduction projection lens system PL are fixed is replaced with nitrogen gas so as to thereby avoid absorption of the pulse illumination light having a wavelength of 193 nm by oxygen. Similar nitrogen gas replacement is performed with respect to the optical path from the interior of the illumination system 10 to the condenser optical system 12.

[0052] The wafer W is held on a wafer holder (chuck) WH. The wafer holder WH attracts the reverse (back) surface of the wafer by vacuum suction. An annular-shaped auxiliary plate portion HRS is provided on a peripheral portion of the wafer holder WH so as to surround the circumference of the wafer W. The height of the surface of the annular-shaped auxiliary plate portion HRS is so as to be substantially flush with the upper surface of the wafer W

attracted to the upper surface of the holder WH. This annular-shaped auxiliary plate portion HRS is used as an alternative focus detection surface if a detection point of a focus sensor is positioned outside the contour edge of the wafer W when a shot area at a peripheral position on the wafer W is scanned and exposed, as described below in detail.

[0053] Further, the annular-shaped auxiliary plate portion HRS can also serve as a flat reference plate (fiducial plate) for calibration of a system offset of the focus sensor in the same manner as disclosed in U.S. Pat. No. 4,650,983 (to Suwa) mentioned above. Needless to say, a special reference plate may be separately provided for calibration of the focus sensor.

[0054] The wafer holder WH is mounted on a ZL stage 30. The ZL stage 30 can translate in the Z-direction along the optical axis AX of the 1/4 reduction projection lens system PL, and which can move in a direction perpendicular to the optical axis AX while tilting with respect to an XY-plane. The ZL stage 30 is mounted on an XY stage 34 through three Z-actuators 32A, 32B, and 32C. The XY stage 34 is movable two dimensionally in X- and Y-directions on a base. Each of the Z-actuators 32A, 32B, and 32C is e.g. a piezoelectric expansion element, a voice coil motor, or a combination of a DC motor and a lift cam mechanism.

[0055] If the three Z-actuators (namely, Z-drive motors) are each driven in the Z-direction to the same amount, the

ZL stage 30 moves translationally in the Z-direction (namely, focusing direction) while being maintained parallel to the XY stage 34. If the three Z-actuators are each driven in the Z-direction by different amounts, an amount and a direction of the tilting of the ZL stage 30 is thereby adjusted.

[0056] The two-dimensional movement of the XY stage 34 is caused by several drive motors 36 which are e.g. a DC motor for rotating a feed screw or a linear motor or the like capable of producing a driving force in a non-contact manner. The drive motors 36 are controlled by a wafer stage controller 35 which is supplied with a measuring coordinate position from a laser interferometer (IFM) 33, so that the wafer stage controller 35 is capable of measuring changes in the position of a reflecting surface of a moving mirror 31 in the X- and Y-directions.

[0057] For example, the entire construction of the XY stage 34 using a linear motor as drive motor 36 may be as disclosed in Japanese Laid-Open Patent Application No.(Sho) 61-209831 (Tateishi Electronics Co.) laid open on Sep. 18, 1986.

[0058] With respect to this embodiment, it is assumed here that the working distance of the 1/4 reduction projection lens system PL is so small that a projected beam of an oblique incident light type focus sensor cannot be led to the wafer surface through the space between the surface of the optical element of the 1/4 reduction

projection lens system PL closest to the image plane and the upper surface of the wafer W. In this embodiment, therefore, three focus detection systems GDL, GDC, and GDR of an off-axis type (having a focus detection point out of the projection field of the 1/4 reduction projection lens system PL) are disposed around a lower end portion of the barrel of the 1/4 reduction projection lens system PL.

[0059] Of these focus detection systems, the detection systems GDL and GDR are set so as to have focus detection points positioned on the front and rear sides of the projection field with respect to the direction of scanning movement of the wafer W at the time of scanning exposure. When one shot area on the wafer W is scanned and exposed, one of the detection systems GDL and GDR selected according to the direction of scanning movement (plus direction or minus direction) is operated so as to previously read the change in the surface height position in the shot area before exposure of the wafer to the rectangular projected image.

[0060] Accordingly, the focus detection systems GDL and GDR function, for example, as the same pre-read sensors as those of a focus detection system disclosed in U.S. Pat. No. 5,448,332 (to Sakakibara et al.). In this embodiment, however, a focus adjustment (or tilt adjustment) sequence different from that of U.S. Pat. No. 5,448,332 is used and a special focus detection system is therefore added to the focus detection systems GDL and GDR. This arrangement is

described below in more detail.

[0061] The focus detection system GDC shown in FIG. 1 has a detection point in a non-scanning direction perpendicular to the scanning direction of the projection field of the 1/4 reduction projection lens system PL as seen on the surface of the wafer W (i.e., in an XY plane) in accordance with the off-axis method. However, the focus detection system GDC has another detection point on the back side of the 1/4 reduction projection lens system PL as viewed in FIG. 1 in addition to its detection point on the front side.

[0062] The focus detection method in accordance with the present invention is characterized in that the off-axis focus detection system GDC and one of the pre-reading focus detection systems GDL and GDR are operated in cooperation with each other. Details of these focus detection systems are described below.

[0063] Information on the height position of a portion of the wafer surface detected by each of the above-described focus detection systems GDL, GDR, and GDC (e.g., an error signal or the like representing the amount of deviation from the best focus position) is input to an automatic focusing (AF) control unit 38. The AF control unit 38 determines an optimal amount of driving of each of the Z-drive motors 32A, 32B, and 32C on the basis of the detection information supplied from the detection systems, and drives the Z-drive motors 32A, 32B, and 32C to perform

focusing and tilt adjustment with respect to the area of the wafer W on which the projected image is to be actually imaged.

[0064] For this control, each of the focus detection systems GDL and GDR is a multi-point focus sensor. Each of the focus detection systems GDL and GDR has detection points at a plurality of positions (e.g., at least two positions) in the rectangular projection area on the wafer W formed by the 1/4 reduction projection lens system PL, and the AF control unit 38 is capable of tilt adjustment of the wafer W at least in the non-scanning direction (X-direction) as well as focusing.

[0065] The aligner shown in FIG. 1 is arranged (constructed) to perform scanning exposure by moving the XY stage 34 at a constant speed in the Y-direction. The relationship of the scanning movement and the stepping movement of the reticle R and the wafer W during scanning exposure will now be described with reference to FIG. 2.

[0066] Referring to FIG. 2, a fore-group lens system LGa and a rear-group lens system LGb represent the 1/4 reduction projection lens system PL shown in FIG. 1; and an exit pupil Ep exists between the fore-group lens system LGa and the rear-group lens system LGb. On the reticle R shown in FIG. 2, a circuit pattern area Pa is formed in a frame defined by a shield band SB. The circuit pattern area Pa has a diagonal length larger than the diameter of the circular image field on the object side of the 1/4

reduction projection lens system PL.

[0067] To the image of the area Pa of the reticle R, a corresponding shot area SAa on the wafer W is exposed in a scanning manner by moving the reticle R at a constant speed Vr in the minus direction along the Y-axis while moving the wafer W at a constant speed Vw in the plus direction along the Y-axis, for example. At this time, the shape of pulse illumination light IA for illuminating the reticle R is set in the form of a parallel strip or a rectangle elongated in the X-direction in the area Pa of the reticle, as shown in FIG. 2. The ends of the shape of pulse illumination light IA are opposite from (opposed to) each other in the X-direction are positioned on the shield band SB.

[0068] A partial pattern contained in the rectangular area in the area Pa of the reticle R irradiated with the pulse illumination light IA is imaged as an image SI at the corresponding position in the shot area SAa on the wafer W by the 1/4 reduction projection lens system PL (fore-group lens system LGa and rear-group lens system LGb). When the relative scanning of the pattern area Pa on the reticle R and the shot area SAa on the wafer W is completed, the wafer W is moved one step, for example, to a certain distance in the Y-direction such that the scanning start position is thereby set with respect to a shot area SAb adjacent to the short area SAa. During this stepping movement (stepping operation), the illumination with pulse illumination light IA is stopped.

[0069] Next, in order to expose the shot area SAb on the wafer W to the image of the pattern in the area Pa of the reticle R in a scanning manner, the reticle R is moved at the constant speed Vr in the plus direction of the Y-axis relative to pulse illumination light IA and the wafer W is simultaneously moved at the constant speed Vw in the minus direction of the Y-axis relative to the projected image SI. The speed ratio Vw/Vr is set to the reduction ratio 1/4 of the 1/4 reduction projection lens system PL. In accordance with the above-described schedule, a plurality of shot areas on the wafer W are exposed to the image of the circuit pattern area Pa of the reticle R.

[0070] The projection aligner shown in FIGS. 1 and 2 can be used as a step-and-repeat aligner in such a manner that, if the diagonal length of the circuit pattern area on the reticle R is smaller than the diameter of the circuit image field of the 1/4 reduction projection lens system PL, the shape and size of the opening of the reticle blind in the illumination system 10 are changed so that the shape of illumination light IA thereby conforms to the circuit pattern area. In such a case, the reticle stage 14 and the XY stage 34 are maintained in a relatively-stationary state during exposure of each of shot areas on the wafer W.

[0071] However, if the wafer W moves slightly during exposure, the slight movement of the wafer W may be measured by the laser interferometer system 33; and the reticle stage 14 may be slightly moved under control so

that the corresponding small error in the position of the wafer W relative to the 1/4 reduction projection lens system PL can be canceled by follow-up correction on the reticle R side. For example, systems for such reticle follow-up correction are disclosed in Japanese Laid-Open Patent Application Nos. (Hei)6-204115 and (Hei)7-220998. Techniques disclosed in these publications may be used according to one's need.

[0072] If the shape or size of the opening of the reticle blind is changed, a zoom lens system may be provided to enable the pulse light reaching the reticle blind from the light source to be concentrated within the range matching with the adjusted opening according to the change in the shape or size of the opening.

[0073] Since the area of the projected image SI is set in the form of a strip or a rectangle elongated in the X-direction as clearly seen in FIG. 2, tilt adjustment during scanning exposure may be effected only along the direction of rotation about the Y-axis, that is, the rolling direction with respect to the scanning exposure direction in this embodiment. Needles to say, if the width of the projected image SI area in the scanning direction is so large to such an extent that there is a need to consider the influence of flatness of the wafer surface with respect to the scanning direction, tilt adjustment in the pitching direction is performed during scanning exposure. This operation will be described in more detail with respect to

another embodiment of the invention.

[0074] The focus detection systems GDL, GDR, and GDC shown in FIG. 1 are disposed as illustrated in FIG. 3, for example. FIG. 3 is a perspective view showing the disposition of detection points of the focus detection systems on the plane on which the circular image field CP of the 1/4 reduction projection lens system PL on the image side is formed. FIG. 3 shows only the disposition of the focus detection systems GDL and GDC. The focus detection system GDR is omitted since it has the same configuration as the detection system GDL.

[0075] Referring to FIG. 3, the focus detection system GDC has two detectors GDC1 and GDC2 which are set so that detection points (detection areas) FC1 and FC2 are positioned on an extension line LLc of the axis of the strip-like of rectangular projected image SI. The strip-shaped rectangular projected image SI extends in the circular field CP of the 1/4 reduction projection lens system PL in a diametrical direction (X- direction). These detectors GDC1 and GDC2 detect the height position of the upper surface of the wafer W (or the auxiliary plate portion HRS) or a positioning error amount in the Z-direction with respect to the best focus plane position.

[0076] On the other hand, the focus detection system GDL includes in the embodiment five detectors GDA1, GDA2, GDB1, GBD2, and GDB3 having respective detection points (detection areas) FA1, FA2, FB1, FB2, and FB3 positioned on

a straight line LLa parallel to the extension line LLc. Each of these five detectors independently detects the height position of a point on the upper surface of the wafer W (or the auxiliary plate portion HRS) or a positioning error amount in the Z-direction with respect to the best focus plane position.

[0077] The extension line LLc and the straight line LLa are set at a certain distance from each other in the scanning direction (Y-direction). Also, the detection point FA1 of the detector GDA1 and the detection point FC1 of the detector GDC1 are set at substantially the same coordinate positions in the X-direction while the detection point FA2 of the detector GDA2 and the detection point FC2 of the detector GDC2 are set at substantially the same coordinate positions in the X-direction.

[0078] The detection points FB1, FB2, and FB3 of three detectors GDB1, GDB2, and GDB3 are disposed so as to cover the area of the strip-like or rectangular projected image SI in the X- direction. That is, the detection point FB2 is disposed at a X-coordinate position corresponding to the center (the point at which the optical axis AX passes) of the area of the projected image SI in the X-direction while the detection points FB1 and FB3 are disposed at X-coordinate positions corresponding to positions in the vicinity of the opposite ends (both ends) of the projected image SI area in the X-direction. Therefore, the three detection points FB1, FB2, and FB3 are used for focus error

pre-reading of the surface portion of the wafer W corresponding to the projected image SI area.

[0079] The focus detection system GDR, not shown in FIG. 3, also has three pre-reading detectors GDE1, GDE2, GDE3 and other two detectors FDD1 and GDD2 disposed opposite sides (both sides) of these pre-reading detectors in the X-direction. For ease of explanation, with respect to this embodiment, it is assumed that the planes recognized as best focus positions by the twelve detectors GDA1, GDA2; GDB1, GDB2, GDB3; GDC1, GDC2; GDD1, GDD2; GDE1, GDE2, GDE3 are adjusted to one XY-plane. That is, no system offset is provided between the twelve detectors and it is assumed that the surface height positions of the wafer W detected at the twelve detection points FA1, FA2; FB1, FB2, FB3; FC1, FC2; FD1, FD2; FE1, FE2, FE3 as positions at which the detected focus error becomes zero coincide closely with each other.

[0080] For the above-described twelve focus detectors, optical sensors, air micrometer type sensors, electrostatic capacity type gap sensors or the like can be used if the end of the 1/4 reduction projection lens system PL is not immersed in a liquid. However, if an immersion projection system is formed, it is, of course, impossible to use air micrometer type sensors.

[0081] FIG. 4 is a block diagram of an example of the AF control unit 38 for processing detection signals (error signals) from the focus detection systems GDL, GDR, and GDC

shown in FIGS. 1 and 3. As shown in FIG. 4, one of the group of detection signals from the five detectors GDA1, GDA2, GDB1, GDB2, and GDB3 of the pre-reading focus detection systems GDL and the group of detection signals from the five detectors GDD1, GDD2, GDE1, GDE2, and GDE3 of the focus detection systems GDR are selected by a changeover circuit 50 to be supplied to subsequent processing circuits.

[0082] The changeover circuit 50 selects the signals from one of the focus detection systems GDL and GDR in response to a changeover signal SS1 (representing a direction discrimination result) supplied from a position monitor circuit 52. The position monitor circuit 52 discriminates one scanning movement direction of the wafer stage 34 from the other on the basis of stage control information from the wafer stage controller 35, and the position monitor circuit 52 monitors changes in the moved position of the wafer W from the pre-read position to the exposure position. In the state shown in FIG. 4, the changeover circuit 50 is selecting the five detection signals from the focus detection system GDL.

[0083] The detection signals from the pre-reading detectors GDB1, GDB2, and GDB3 with respect to the exposure area (projected image SI) are supplied to a first calculator 54 for calculating a focus error amount and a tilt error amount. The first calculator 54 supplies, to a second calculation and memory circuit 56, error data DT1

and DT2 on focus error amount ΔZf and tilt error amount ΔTx (fine inclination about the Y-axis) of the surface area of the wafer W previously read at the three detection points FB1, FB2, and FB3.

[0084] On the other hand, the detectors GDA1 and GDA2 supplies the second calculation and memory circuit 56 with information ZA1 and information ZA2. The information ZA1 and information ZA2 represent the surface height positions (or focus deviations) at the detection points FA1 and FA2, respectively. The detection of the information ZA1 and information ZA2 is performed simultaneously with the detection of the wafer surface by the three detectors GDB1, GDB2, and GDB3.

[0085] The second calculation and memory circuit 56 calculates, on the basis of error data DT1, DT2, information ZA1, ZA2 and the relative positional relationship between the detectors, target values $\Delta Z1$ and $\Delta Z2$ of the height position of the wafer W which should be detected at the detection points FC1 and FC2 of the detectors GDC1 and GDC2 set at the projection exposure position with respect to the Y-direction (scanning direction). The second calculation and memory circuit 56 temporarily stores the calculated target values $\Delta Z1$ and $\Delta Z2$.

[0086] The meaning of the target values $\Delta Z1$ and $\Delta Z2$ is as follows. That is, if information ZC1 and information ZC2 detected by the detectors GDC1 and GDC2 when the

surface portions of the wafer W (or annular-shaped auxiliary plate portion HRS) previously read at the pre-reading detection points FA1 and FA2 reach the detection points FC1 and FC2 corresponding to the exposure position are equal to the target values ΔZ1 and ΔZ2, respectively, then both the focus error amount ΔZf and tilt error amount ΔTx determined by pre-reading become zero at the exposure position.

[0087] Further, the second calculation and memory circuit 56 outputs the stored target values ΔZ1 and ΔZ2 to a third calculation and drive circuit 58 immediately before the pre-read area on the wafer with respect to the Y-direction arrives at the exposure position at which the projected image SI is exposed.

[0088] Accordingly, in synchronization with a signal SS2 output from the position monitor circuit 52, the second calculation and memory circuit 56 outputs signals representing target values ΔZ1 and ΔZ2 which are temporarily stored to the third calculation and drive circuit 58. The signals representing target values ΔZ1 and ΔZ2 are delayed by an amount of time determined by the distance between the straight line LLa and the extension line LLc in the Y-direction and the speed of movement of the wafer W, and then the signals are output to the third calculation and drive circuit 58.

[0089] If signal SS2 is output each time the wafer W is moved to be scanned through a distance corresponding to the

width of the projected image SI in the scanning direction, a certain number of sets of target values ΔZ1 and ΔZ2 (e.g., five sets) corresponding to a number obtained by dividing the distance between the straight line LLa and the extension line LLc in the Y-direction (e.g., about 40 mm) shown in FIG. 3 by the width of the projected image SI (e.g., about 8 mm) are stored in the second calculation and memory circuit 56. Accordingly, the second calculation and memory circuit 56 functions as a memory for storing target values ΔZ1 and ΔZ2 in a first in-first out (FIFO) manner.

[0090] The third calculation and drive circuit 58 reads, in response to a signal SS3 from the position monitor circuit 52, detection information ZC1 and ZC2 on the height position of the surface of the wafer W (or annular-shaped auxiliary plate portion HRS) detected by the detectors GDC1 and GDC2. Immediately after this, the area on the wafer W detected at the pre-read position reaches the exposure position (the position of the projected image SI).

[0091] Simultaneously, the third calculation and drive circuit 58 reads the data of target values ΔZ1 and ΔZ2 (corresponding to the exposure position) output from the second calculation and memory circuit 56; and the third calculation and drive circuit 58 determines, by calculation, drive amounts (amounts of position adjustment or amounts of speed adjustment) corresponding to the Z-drive motors 32A, 32B, and 32C shown in FIG. 1 on the basis of the detection information ZC1 and ZC2 and the target

values ΔZ1 and ΔZ2, and then outputs determined drive amount data to the Z-drive motors 32A, 32B, and 32C.

[0092] It is to be understood that most of the element of FIG. 4 may be embodied in a programmed microcontroller or microprocessor, executing a suitable program which could be written by one of ordinary skill in the art in light of FIG. 4.

[0093] FIG. 5 is a plan view explaining the function of the annular-shaped auxiliary plate portion HRS formed at the peripheral portion of the wafer holder WH as shown in FIG. 1. In this embodiment, since all the detection points of the focus detection systems are positioned outside the projection field CP of the 1/4 reduction projection lens system PL as described above, there is a possibility that some of the focus detection points are located outside the perimeter of wafer W at the time of scanning exposure of some of a plurality of shot areas SAn on the wafer arranged at the peripheral portion of the wafer W.

[0094] For example, as shown in FIG. 5, when a peripheral shot area SA1 of the wafer W positioned on the holder WH by using a prealignment notch NT is scanned and exposed, the end focus detection point FA1 (or FD1) of the pre-reading focus detection system GDL (or GDR) and the detection point FC1 of the exposure position focus detection system GDC are located outside the wafer W. In this state, it is normally difficult to perform focusing and tilt adjustment.

[0095] A main function of the annular-shaped auxiliary plate portion HRS is enabling normal focusing and tiling in such a situation. As shown in FIG. 5, the detection point FA1 (or FD1) and the detection point FC1 located outside the of the wafer W are set so as to be positioned on the surface of the annular-shaped auxiliary plate portion HRS. Accordingly, it is desirable that the height of the surface of the annular-shaped auxiliary plate portion HRS is substantially equal to that of the surface of the wafer W.

[0096] More specifically, the surface of the wafer W and the surface of the annular-shaped auxiliary plate portion HRS are made flush with each other within the detection ranges which correspond to the detection points FA1 (FA2), FC1 (FC2), and FD1 (FD2) and in which the desired linearity of the focus detectors corresponding to the detection points are ensured. Further, since the surface of the annular-shaped auxiliary plate portion HRS is used as an alternative to the surface of the wafer W, its reflectivity is set on the same order or to the same value as the reflectivity of a standard (silicon) wafer. For example, a mirror-finished surface is preferred as the annular-shaped auxiliary plate portion HRS.

[0097] If the wafer W (on wafer holder WH) is moved to be scanned in the direction of the arrow shown in FIG. 5, the detection points FA1, FA2; FB1, FB2, FB3 of the focus detection system GDL are selected as pre-reading sensors with respect to the shot area SA1. In this case, provided

that the distance between the extension line L1c corresponding to the center of the projected image SI in the Y-direction and the straight line LLa on which the detection points of the focus detection system GDL are disposed is D1a and provided that the distance between the extension line LLc and the straight line LLb on which the detection points of the other focus detection system GDR are disposed is DLb, then DLa and D1b are set so that DLa is approximately equal to DLb in this embodiment. From the speed Vw of the wafer W at the time of scanning exposure, the delay time Δt taken for the focus pre-read position on the wafer W to reach the exposure position is Δt=DLa/Vw (sec.). Accordingly, the time for temporary storage of the target value data ΔZ1 and ΔZ2 in the second calculation and memory circuit 56 shown in FIG. 4 is substantially equal to the time lag Δt.

[0098] However, the distance DLa and the distance DLb may be selected so that DLa does not equal DLb according to a restriction relating the construction of the aligner. Needless to say, in such a case, the delay time of supply of the target values ΔZ1 and ΔZ2 are set to different lengths with respect to use of the pre-reading focus detection system GDL and use of the focus detection system GDR.

[0099] The focusing and tilting operations of the first embodiment arranged (constructed) as described above is now described with reference to FIGS. 6A through 6D. FIG. 6A

schematically shows a state of the upper surfaces of the wafer W and the annular-shaped auxiliary plate portion HRS detected by the pre-reading focus detection system GDL at an instant during scanning exposure of the peripheral shot area SA1 of the wafer W as shown in FIG. 5.

[0100] In FIGS. 6A through 6D, a horizontal line BFP represents the optimum focus plane of the 1/4 reduction projection lens system PL. The detector GDB1 that detects the position of the wafer surface in the Z-direction at the focus detection point FB1 in the shot area SA1 outputs a detection signal representing ΔZB1 as a Z- position error (amount of defocusing) of the wafer surface with respect to the plane BFP. Similarly, the detectors GDB2 and GDB3 that detect errors of the position of the wafer surface in the Z-direction at the focus detection points FB2 and FB3 output detection signals representing errors ΔZB2 and ΔZB3. Each of these Z-position errors has a negative value if the wafer surface is lower than the best focus plane BFP, or has a positive value if the wafer surface is higher than the best focus plane BFP.

[0101] The values of these errors ΔZB1, ΔZB2, and ΔZB3 are input to the first calculation and memory circuit 54 shown in FIG. 4. The first calculation and memory circuit 54 determines parameters of an equation representing an approximate plane APP (actually an approximate straight line) shown in FIG. 6B of the entirety of the pre-read portion in the shot area SA1, by the method of least

squares or the like on the basis of these error values. The parameters thereby determined are focus error amount ΔZf and tilt error amount ΔTx of the approximate plane APP, as shown in FIG. 6B. The values of the error amount ΔZf and the amount ΔTx thus calculated are output as the data DT1 and DT2 to the second calculation and memory circuit 56. In this embodiment, the focus error amount ΔZf is calculated as an error substantially at the middle point (corresponding to detection point FB2) of the shot area SA1 in the X-direction.

[0102] When the detectors GDB1, GDB2, and GDB3 detect Z-position errors as described above, the detectors GDA1 and GDA2 simultaneously detect Z-position errors ΔZA1 and ΔZA2 of the wafer surface or the surface of the annular-shaped auxiliary plate portion HRS with respect to the best focus plane at the detection points FA1 and FA2. These errors ΔZA1, ΔZA2 are temporarily stored in the second calculation and memory circuit 56.

[0103] Immediately after the detection and storage, assuming that the approximate plane APP such as that shown in FIG. 6B is corrected so as to coincide with the best focus plane BFP as shown in FIG. 6C, that is, the wafer holder WH is adjusted in the Z-direction and the tilting direction so that ΔZf=0 and ΔTx=0, then the second calculation and memory circuit 56 calculates the Z-position target value ΔZ1 to be detected at the detection point FA1 and the Z-position target value ΔZ2 to be detected at the

detection point FA2 on the basis of the data DT1 and DT2 (error amount ΔZf and ΔTx), the Z-position errors ΔZA1, ΔZA2 actually measured at the detection points FA1 and FA2 and the distance DS between the middle point of the shot area and each of the detection points FA1 and FA2 in the X-direction. The calculated Z-position target values ΔZ1 and ΔZ2 are temporarily stored in the second calculation and memory circuit 56 until the pre-read area on the wafer W reaches the area of the projected image SI (exposure position).

[0104] When the pre-read area on the wafer W reaches the exposure position, the third calculation and drive circuit 58 shown in FIG. 4 reads the detection signals from the focus detectors GDC1 and GDC2 for detecting Z-position errors at the detection points FC1 and FC2. If, for example, the pre-read area on the wafer W is in a state such as shown in FIG. 6D immediately before it reaches the exposure position, the detector GDC1 outputs detection signal ZC1 representing a Z-position error at the detection point FC1 while the detector GDC2 outputs detection signal ZC2 representing a Z-position error at the detection point FC2.

[0105] Then the third calculation and drive circuit 58 calculates the drive amounts for the three Z-actuators 32A, 32B, and 32C necessary for tilting the wafer holder WH and/or translating the wafer holder WH in the Z-direction so that the values of the detection signals ZC1 and ZC2

supplied from the detectors GDC1 and GDC2 become respectively equal to the Z-position target values ΔZ1 and ΔZ2 which are supplied, in a delaying manner, from the second calculation and memory circuit 56. The third calculation and drive circuit 58 supplies the Z-actuators 32A, 32B, 32C with signals corresponding to the calculated drive amounts.

[0106] The shot area SA1 of the upper surface of wafer W is thereby precisely adjusted to coincide with the best focus plane BFP at the exposure position. As a result, the projected image SI of the pattern of the reticle R to be maintained in an optimal imaged state is exposed in the scanning mode of the shot area.

[0107] For this operation in the first embodiment, each of the detectors in the pre-reading focus detection system GDL and each of the detectors in the exposure position focus detection system GDC are set (calibrated) so as to output a detection signal indicating that there is no focus error when the surfaces of the wafer W or the annular-shaped auxiliary plate portion HRS coincide with the best focus plane BFP. However, it is difficult to strictly set the detectors in such a state. In particular, a detection offset between the detectors GDA1 and GDA2 (GDD1 and GDD2) in the pre-reading focus detection system GDL (GDR) and the exposure position focus detectors GDC1 and GDC2 steadily defocuses the pattern image which is formed on the wafer W for the exposure.

[0108] Therefore, an offset value between the height position in the Z-direction at which the detector GDC1 detects the zero focus error and the height position in the Z-direction at which the detector GDA1 (GDD1) detects the zero focus error may be measured and stored by simultaneously performing focus detection by these detectors on an extremely high flatness surface of a reflective glass plate (namely, fiducial plate) provided on the wafer holder WH. This surface may be structure HRS or another structure separate from structure HRS. As a result, the correction by the stored offset value may be made when the Z-actuators 32A, 32B, and 32C are drive on the basis of the Z-position errors detected by the exposure position focus detectors GDC1 and GDC2.

[0109] The construction of a focus and tilt sensor in accordance with a second embodiment of the present invention is next described with reference to FIGS. 7 and 8. With respect to the second embodiment, a situation is supposed in which the projected image SI contained in the circular field of the 1/4 reduction projection lens system PL has a comparatively large maximum width in the Y-direction (scanning direction) such that the influence of a tilt of the surface of wafer W in the Y-direction, i.e., pitching, is considerable.

[0110] As shown in FIG. 7, an exposure position focus detector GDC1 (not illustrated) is provided. The exposure position focus detector GDC1 has two detection points FC1a

and FC1b disposed symmetrically about extension line LLc in the Y-direction above the projected image SI. Further, another exposure position focus detector GDC2 (not illustrated) is provided. The exposure position focus detector GDC2 has two detection points FC2a and FC2b disposed symmetrically about extension line LLc in the Y-direction below the projected image SI. Furthermore, a pre-reading focus detector GDA1 and a pre-reading focus detector GDA2 (not illustrated) are provided. The pre-reading focus detector GDA1 has two detection points FA1a and FA1b disposed symmetrically about straight line LLa in the Y-direction. The pre-reading focus detector GDA2 has two detection points FA2a and FA2b disposed symmetrically about the straight line LLa in the Y- direction. Similarly, a pre-reading focus detector GDD1 (not illustrated) and a pre-reading focus detector GDD2 are provided. The pre-reading focus detector GDD1 has two detection points FD1a and FD1b disposed symmetrically about straight line LLb in the Y-direction; and the pre-reading focus detector GDD2 has two detection points FD2a and FD2b disposed symmetrically about the straight line LLb in the Y-direction.

[0111] Further, pre-reading focus detectors GDBn (n=1, 2, 3) (not illustrated) and pre-reading focus detectors GDEn (n=1, 2, 3) (not illustrated) are also provided. The pre-reading focus detectors GDBn has a plurality of pairs of detection points FB1a, FB1b; FB2a, FB2b; FB3a, FB3b.

The pre-reading focus detectors GDEn has a plurality of pairs of detection points FE1a, FE1b; FE2a, FE2b; FE3a, FE3b. Each of the pairs of detection points are spaced apart from each other in the Y-direction.

[0112] The focus detection system shown in FIG. 7 reproduces adjustment amounts (i.e., target values ΔZ1 and ΔZ2) necessary for correcting the pre-read surface configuration (i.e., error amount ΔZf and ΔTx) of each of the shot areas at the detection points of the off-axis detectors GDC1 and GDC2 in the same manner as the above-described first embodiment, thereby enabling focus adjustment in the Z-direction and tilt adjustment in the X-direction (rolling direction) of the exposure area.

[0113] In this embodiment, the pre-reading focus detection system GDL (GDR) and the exposure position focus detection system GDC have a plurality of pairs of detection points (FAna and FAnb; Fbna and FBnb; FCna and FCnb; FDna and FDnb; FEna and FEnb) spaced apart by a certain distance in the Y-direction. Accordingly, a tilt error amount ΔTy of the pre-read shot area in the pitching direction can be detected from the differences between Z-position errors at the detection points (. . . na, . . . nb) forming the pairs in the Y-direction, and adjustment amounts (i.e., target values ΔZA1, ΔZA2) necessary for correcting the surface configuration of the shot area including of the tilt error amount ΔTy, can be reproduced at the detection points (FCna and FCnb) of the off-axis detectors GDC1 and GDC2.

[0114] The detectors GDB1, GDB2, and GDB3 for detecting the focus positions at the detection positions FB1, FB2, and FB3 shown in FIG. 3 are disposed as systems independent of each other by being fixed to a lower portion of the 1/4 reduction projection lens system PL. However, at least these three detectors GDB1, GDB2, and GDB3 may be arranged to detect the focus positions at the detection points FB1, FB2, and FB3 through a common objective lens system. The same can also be said with respect to the group of three detectors GDE1, GDE2, and GDE3 for detecting the focus positions at the detection points FE1, FE2, and FE3 shown in FIG. 5.

[0115] Further, a common objective lens system may be used for the same purpose with respect to the group of six detectors for detecting the focus positions at the six detection points Fbna and FBnb (n=1, 2, 3) shown in FIG. 7 or for the other group of six detectors for detecting the focus positions at the six detection points FEna and FEnb (n=1, 2, 3). An arrangement or construction of using a common objective lens system for detectors for detecting the focus positions at a plurality of detection points is therefore described briefly with reference to FIG. 8.

[0116] FIG. 8 is a schematic side view of the positional relationship between the projection lens and the detectors corresponding to the six detection points FBna and FBnb (n=1, 2, 3) and the four detection points FA1a, FA1b, FA2a, and FA2b shown in FIG. 7 as seen in the Y-direction in FIG.

7. Accordingly, the scanning direction of the wafer W in FIG. 8 is a direction perpendicular to the plane of the figure and the five detection points FA1a, FBna (n=1, 2, 3), and FA2a arranged in a row in the X direction at the leftmost position in FIG. 7 are representatively shown in FIG. 8. Another row of detection points FA1b, FBnb (n=1, 2, 3); and FA2b are adjacent to the five detection points FA1a, FBna (n=1, 2, 3), and FA2a (in a direction perpendicular to paper of FIG. 8). In this embodiment, the focus positions at these ten points are detected through the objective lens system.

[0117] As shown in FIG. 8, illumination light ILF from an illumination optical system 80A including a light source (e.g. a light emitting diode, a laser diode, a halogen lamp or the like) is emitted through each of ten small slits formed in a multi-slit plate 81A. The light source is capable of emitting light in a wavelength range to which the resist layer on wafer W is not sensitive. The ten small slits are disposed in correspondence with the ten detection points FBna, FBnb (n=1, 2, 3), FA1a, FA1b, FA2a, and FA2b set on the wafer W. The light transmitted through the small slits is incident upon an objective lens 84A of a projection system via a lens system 82A and a reflecting mirror 83A and is deflected by a prism 85A by a desired angle to form a slit image at each of the detection points.

[0118] The illumination optical system 80A, the multi-slit plate 81A, the lens system 82A, the reflecting mirror

83A, the objective lens 84A and the prism 85A constitute a projection system of an oblique incident light type focus detection unit. The solid lines in the optical path from the multi-slit plate 81A to the wafer W shown in FIG. 8 represent principal rays of transmitted light from the small slits, and the broken lines in the optical path represent typical imaging rays S1f of the small slit imaging light imaged at the detection point FB2a (or FB2b).

[0119] The reflected light of the small slit imaging light reflected at each of the detection points on the wafer W is again imaged on a receiving slit plate 81B via a prism 85B, an objective lens 84B, a reflecting mirror 83B and a lens system 82B disposed generally symmetrically with respect to the projection system. Ten small receiving slits disposed in correspondence with the small slits in the projection multi- slit plate 81A are formed in the receiving slit plate 81B. The light transmitted through these receiving slits is received by a light receiving device 80B which is a plurality of photoelectric detection elements.

[0120] As the photoelectric detection elements of the light receiving device 80B, ten photoelectric detection elements are provided in correspondence with the positions of the small slits of the receiving slit plate 81B to separately detect the focus positions at the detection points on the wafer. The light receiving device 80B, the receiving slit plate 81B, the lens system 82B, the

reflecting mirror 83B, the objective lens 84B and the prism 85B constitute a light receiving system of the oblique incident light type focus detection unit. The solid lines in the optical path from the wafer W to the receiving slit plate 81B shown in FIG. 8 represent principal rays of the small slit images normally reflected by the wafer W; and the broken lines in the optical path represent typical imaging rays RSf from the detection point FB2a (or FB2b) to the receiving slit plate 81B.

[0121] The projection system and the receiving system shown in FIG. 8 are mounted on an integrally-formed metal member so that the positions of the components are accurately maintained relative to each other. The metal member is rigidly fixed on the lens barrel of the 1/4 reduction projection lens system PL. Another focus detection unit constructed in the same manner is disposed on the opposite side of the 1/4 reduction projection lens system PL to separately detect the focus positions at the ten detection points FEna, FEnb (n=1, 2, 3), FD1a, FD2a, FD1b, and FD2b shown in FIG. 7.

[0122] With respect to the pair of detection points FC1a and FC1b and the pair of detection points FC2a and FC2b shown in FIG. 7, oblique incident light type focus detection units each having a projection system and a receiving system arranged in the Y-direction of FIG. 7 (direction perpendicular to paper in FIG. 8) may be provided on the opposite sides (both sides) of the 1/4

reduction projection lens system PL in the X-direction. Also in a case where the focus position detection points are disposed as shown in FIG. 5, the oblique incident light type focus detection unit shown in FIG. 8 can also be applied in the same manner.

[0123] A scanning aligner to which the present automatic focusing/tilt control system is applied is next described in accordance with a third embodiment of the present invention with reference to FIG. 9. This embodiment is applicable to a scanning aligner for a large substrate e.g. 300 mm diameter or greater having a 1X projection optical system. The 1X projection optical system is formed of a tandem (vertically arranged) combination of a first-stage Dyson type (catadioptric) projection imaging system and a second-stage Dyson type projection imaging system. The first-stage Dyson type (catadioptric) projection imaging system is provided with a pair of prism mirrors PM1 and PM2, a lens system PL1 and a concave mirror MR1; and the second-stage Dyson type projection imaging system is provided with a pair of prism mirrors PM3 and PM4, a lens system PL2 and a concave mirror MR2. Such an aligner is disclosed in U.S. Pat. No. 5,298,939 (to Swanson et al.), for example.

[0124] In the aligner shown in FIG. 9, a mask M provided as an original plate and a plate P provided as a photosensitive substrate are integrally supported on a carriage 100. A pattern on the mask M is transferred onto

the plate P as a 1X (unit magnification) erect image by moving the carriage 100 to the left or right as viewed in FIG. 9 relative to the projection field of the 1X projection optical system and by moving illumination light IL so as to scan the mask M and plate P.

[0125] In the case of the projection optical system for this type of aligner, it is desirable to minimize the spacing between the incidence plane of the prism mirror PM1 and the surface of the mask M and the spacing between the exit plane of the prism mirror PM4 and the upper surface of the plate P for reducing deteriorations in imaging performance (various aberrations and image distortion). In other words, if these spacings can be sufficiently reduced, the design of the lens systems PL1 and PL2 disposed on the optical axes AX1 and AX2 becomes easier. Therefore, to achieve the desired imaging performance, it is necessary to reduce the spacing between the prism mirror PM1 and the mask M and the spacing between the prism mirrors PM4 and the plate P.

[0126] In view of this condition, for focusing and tilt adjustment of the pattern image projected by this projection, there are provided prereading focus detection systems GDL and GDR and an exposure position off-axis type focus detection system GDC such as those of the first embodiment (FIG. 3) or the second embodiment (FIGS. 7, 8) around the prism mirror PM4 as shown in FIG. 9 to thereby precisely coincide the surface of the plate P and the best

focus plane BFP at the exposure position immediately below the prism mirror PM4, by slightly moving the plate P in the Z-direction and the tilting direction.

[0127] Further, pre-reading focus detection systems GDL' and GDR' and an exposure position off-axis type focus detection system GDC' may be disposed around the prism mirror PM1 on the mask M side so as to face the mask M, as shown in FIG. 9. These focus detection systems make it possible to detect a focus error and a tilt error of the area of the mask M, irradiated with illumination light IL, with respect to the prism mirror PM1 and to measure, at a same time with this, a small deviation in the Z-direction (a focus shift of the image plane) and a tilt deviation (inclination of the image plane) of the best focus plane (i.e., a conjugate plane of reticle R) formed at a predetermined working distance from the prism mirror PM4.

[0128] Thus, in the aligner shown in FIG. 9, the image plane on which the pattern of the mask M is projected and imaged in an optimal condition by the projection optical system and the surface of the plate P can be adjusted to coincide with each other highly accurately during scanning exposure.

[0129] The aligner shown in FIG. 9 may be constructed so that mask M and plate P stand vertically. FIG. 10 is a perspective view of an exemplary structure of a scanning aligner having a vertical carriage, namely, a vertically disposed carriage. The carriage vertically holds mask M

and plate P and integrally moves mask M and plate P with respect to a projection optical system for enabling the scanning. A scanning aligner having mask M and plate P held vertically in this manner is disclosed in Japanese Laid-Open Patent Application No. (Hei) 8-162401, for example.

[0130] Referring to FIG. 10, the entirety of the vertical type scanning aligner is constructed on a fixed base 120A which is placed on a floor with vibration isolators interposed between four corner portions of the fixed base 120A and the floor. Side frame portions 121A and 121B are provided on opposite side portions of the fixed base 120A so as to stand vertically (in the X-direction). A mask M is placed inside the side frame portion 121A while a plate P is placed inside the side frame portion 121B. In the side frame portion 121A, therefore, an opening is formed in which an end portion of an illumination unit 122 is inserted, as illustrated. The illumination unit 122 has an optical system for illuminating mask M with exposure illumination light and for mask-plate alignment.

[0131] A guide base portion 123 is provided on the fixed base 120A so as to extend in the scanning direction (Y-direction) between the side frame portions 121A and 121B. Two straight guide rails 123A and 123B are formed on the guide base portion 123 so as to extend in the Y-direction parallel to each other. A vertical carriage 125 is

supported by fluid bearings or magnetic floating bearings on the guide rails 123A and 123B to be reciprocatingly movably in the Y-direction. The vertical carriage 125 is driven in the Y-direction in a non-contact manner by two parallel linear motors 124A and 124B having stators fixed on the guide base portion 123.

[0132] The vertical carriage 125 has a mask-side carriage portion 125A and a plate-side carriage portion 125B. The mask-side carriage portion 125A is vertically formed inside the side frame portion 121A to hold mask M. The plate-side carriage portion 125B is vertically formed inside the side frame portion 121B to hold plate P. A mask table 126A is provided on the mask-side carriage portion 125A. The mask table 126A is capable of slightly moves mask M in the X- or Y- direction in an XY-plane or in a rotational (θ) direction and is capable of slightly moving mask M in the Z-direction while holding mask M. On the other hand, a plate stage 126B is provided on the plate-side carriage portion 125B. The plate stage 126B is capable of slightly moving plate P in the X- or Y-direction in an XY-plane or in a rotational (θ) direction and is capable of slightly moving plate P in the Z-direction while holding plate P.

[0133] A projection optical system PL such as one disclosed in Japanese Laid-Open Patent Application No. (Hei)8-162401 mentioned above is used in this embodiment. The projection optical system PL is constructed by

arranging a plurality of sets (e.g., seven sets) of "1X" erect type double Dyson systems in the direction perpendicular to the X-direction. The plurality of sets of double Dyson systems are integrally combined and housed in a casing which is generally T-shaped as viewed in an XZ-plane. The projection optical system PL thus constructed is mounted by being suspended from upper end portions of the opposite side frame portions 121A and 121B so that predetermined working distances from mask M and plate P are thereby maintained.

[0134] In the entire casing of the projecting optical system PL, mask M-side focus detection systems GDC', GDL', and GDR' on the mask M side and plate P-side focus detection systems GDC, GDL, and GDR are provided so as to face mask M and plate P, respectively, as shown in FIG. 9. The detection points defined by the pre-reading focus detection systems GDL, GDL', GDR, and GDR' may be set in correspondence with the projection fields of the plurality of sets of double Dyson systems or may be arranged at predetermined intervals irrespective of the placement of the projection fields.

[0135] FIG. 11 is a perspective view of an example of a layout of detectors in mask M-side focus detection systems GDC', GDL', and GDR' provided in the casing of the projection optical system PL shown in FIG. 10. The effective projection fields DF1, DF2, DF3, DF4, DF5, . . . of the plurality of sets of double Dyson systems are set as

trapezoidal areas elongated in the X-direction perpendicular to the scanning direction. The trapezoidal projection fields DFn (n=1, 2, 3 . . .) are arranged in such a manner that the trapezoidal projection fields of each adjacent pair of double Dyson systems overlap each other by their oblique sides as seen in the X-direction.

[0136] While only the projection fields DFn on the mask M side are illustrated in FIG. 11, the projection fields on the plate P side are also arranged in the same manner. For example, the projection field DF2 shown in FIG. 11 is defined by a double Dyson system such as that shown in FIG. 9 including two concave mirrors MR2a and MR2b; and the projection field DF4 is defined by a double Dyson system including two concave mirrors MR4a and MR4b.

[0137] As shown in FIG. 11, detectors GDA1', GDB1', GDB2' . . . , GDA2' (detectors GDA2' not being seen in FIG. 11) for the pre-reading focus detection system GDL' and detectors GDD1', GDE1', GDE2' . . . , GDD2' (detectors GDD2' not being seen in FIG. 11) for the pre-reading focus detection system GDR' are disposed on the opposite sides (on the front and rear sides with respect to the scanning direction) of the plurality of projection fields DFn. Also, exposure position focus detectors GDC1' and GDC2' (detector GDC2' not being seen in FIG. 11) are disposed at the opposite ends of the entire array of the plurality of projection fields DFn in the X-direction perpendicular to the scanning direction.

[0138] Each of the focus detectors described above is e.g. an air micrometer type electrostatic gap sensor. The focus detectors may alternatively be oblique incident light type focus detectors. While only the focus detectors for detection on the mask M side are illustrated in FIG. 11, a plurality of detectors are also arranged in the same manner in the focus detection systems GDC, GDL, and GDR for detection of the plate P.

[0139] Adjustment portions KD1 and KD2 for adjusting various optical characteristics of the plurality of sets of double Dyson systems are provided on side portions of the casing of the projection optical system PL shown in FIG. 11. Therefore, a mechanism is provided to adjust the Z-direction position, i.e., to set a mechanical (optical) focus offset detected as a best focus plane by each focus detector, if the position of the best focus plane on the mask M side or plate P side is changed in the Z-direction in FIG. 11 by the optical characteristic adjustment.

[0140] This mechanism may be e.g. a mechanism which mechanically adjusts the position of a focus detector in the Z direction, or a mechanism which optically adjusts the position recognized as the best focus position by the focus detector in the Z direction, so that the optical path length is changed optically. Alternatively, the mask or plate are automatically adjusted for focusing in the Z direction according to detection signals which represent a focus error, and an offset is added to its moved position

in the Z direction.

[0141] A fourth embodiment in accordance with the present invention is next described with reference to FIG. 12. This embodiment is applicable to an apparatus for performing projection exposure while immersing a projection end portion of a projection lens system PL in a liquid as described above. FIG. 12 is a cross-sectional view of a portion of the apparatus from the end of the projection lens system PL and to a wafer holder WH.

[0142] A positive lens element LE1 having a flat lower surface Pe and a convex upper surface is fixed on the end of the projection lens system PL inside the lens barrel. The lower surface Pe of this lens element LE1 is finished so as to be flush with the end surface of the extreme end of the lens barrel, so that a flow of a liquid LQ is disturbed only to a minimal extent. To a lens barrel end portion of the projection lens system PL immersed in liquid LQ, detectors of pre-reading focus detection systems GDL and GDR and an exposure position focus detection system GRD which are similar to those shown in FIG. 1 are attached so that their extreme end portions are immersed in liquid LQ, as a result.

[0143] A plurality of attraction surfaces 113 for attracting the reverse surface (back surface) of wafer W by vacuum suction are formed in a central inner bottom portion of the wafer holder WH. More specifically, the attraction surfaces 113 is provided with a plurality of circular-band-

like land portions which have a height of about 1 mm and which are formed concentrically with each other with a predetermined pitch in the diametrical direction of the wafer W. Each of the grooves formed in central portions of the circular land portions communicates with a tubing 112 in the wafer holder WH. The piping 112 is connected to a vacuum source for vacuum suction.

[0144] In this embodiment, the spacing (substantial working distance) between the lower surface Pe of the lens element LE1 at the end of the projection lens system PL and the upper surface of the wafer W (or of the auxiliary plate portion HRS) in an optimum focus state, i.e., the thickness of liquid LQ in which a projection optical path is formed, is set to be 5 mm or less. Accordingly, the depth Hq of liquid LQ filling the wafer holder WH may be two to several times larger than this thickness (5 mm or less); and the height of a wall portion LB vertically formed at the peripheral end of the wafer holder WH is about 10 to 25 mm. Thus in this embodiment, the thickness of liquid LQ in the imaging optical path corresponding to the working distance of the projection lens system PL is reduced, so that the total volume of liquid LQ filling the wafer holder WH is smaller and hence temperature control of the liquid [LQ] is easier.

[0145] In the region of liquid LQ in which the projection optical path is formed, a part of the illumination energy is absorbed when exposure light passes

therethrough, so that an irradiation heat fluctuation can easily occur. If the depth Hq of liquid LQ is small, an increase in temperature due to such irradiation heat fluctuation occurs easily and an adverse effect of reducing the stability of temperature control may result. In such a case, a better effect is obtained by setting the depth Hq of liquid LQ to a value several times the substantial working distance, in order to disperse the influence of irradiation heat fluctuation in the large-volume liquid layer.

[0146] To provide focus detection systems GDL, GDR, and GDC as an optical type detection system in an immersion projection system such as that shown in FIG. 12, the projected beam obliquely incident upon the surface of wafer W or of the auxiliary plate portion HRS and the beam reflected by this surface are prevented from intersecting the interface between liquid LQ and air. An example of a focus/tilt detection system suitable for such an immersion projection type aligner is therefore described with reference to FIG. 13.

[0147] FIG. 13 shows the construction of a focus detection system GDL disposed in the vicinity of a projection lens system PL. Other detection systems GDR and GDC are constructed in the same manner as the detection system GDL. In FIG. 13, the same components as those shown in FIG. 12 are indicated by the same reference characters or numerals.

[0148] Referring to FIG. 13, a prism mirror 200 formed of a glass block is fixed in the vicinity of a peripheral portion of the projection lens system PL. The prism mirror 200 has a lower portion immersed in liquid LQ. The prism mirror 200 has reflecting surfaces 200a and 200b. A part of each of the reflecting surfaces 200a and 200b is immersed in liquid LQ. The prism mirror 200 also has flat surfaces 200c and 200d through which the projected beam or reflected beam travels out of the glass of the prism mirror 200 into liquid LQ or out of liquid LQ into the glass. Also the prism mirror 200 has a flat upper surface.

[0149] A multi-slit plate 205 is illuminated, through a condenser lens or a cylindrical lens 203, with light LK (having a non-actinic wavelength with respect to the resist on wafer W) from a light source 202 such as a light emitting diode (LED) or a laser diode (LD) to thereby form a projected beam for focus/tilt detection. A plurality of transmission slits corresponding to detection points (areas) FAn and FBn of the focus detection system GDL are formed in the slit plate 205. The light from each of the transmission slits is reflected by a beam splitter 207 and is incident upon an objective lens 209 to be converged as an imaging beam forming a slit image on the upper surface of wafer W.

[0150] The imaging beam emergent from the objective lens 209 enters the prism mirror 200 through the upper end surface of the same, is normally reflected by the

reflecting surface 200a, and enters liquid LQ through the flat surface 200c to be obliquely incident upon the surface of wafer W to irradiate the same. The beam reflected by wafer W enters the prism mirror 200 through the opposite flat surface 200d, is normally reflected by the reflecting surface 200b and travels out of the prism mirror 200 through the upper end surface. This reflected light beam passes through an objective lens 211 and is reflected by a reflecting mirror 213 disposed at a pupil position of the objective lens 211.

[0151] The beam reflected by the mirror 213 travels reversely through the objective lens 211 and again travels via the reflecting surface 200b and the flat surface 200d of the prism mirror 200 to again irradiate wafer W. The light beam again reflected by wafer W travels via the flat surface 200c and the reflecting surface 200a of the prism mirror 200, passes the beam splitter 207 and is incident on a photoelectric detector 215. The photoelectric detector 215 is a plurality of light receiving elements which receive light corresponding to the slits of the slit plate 205. The photoelectric detector 215 separately outputs detection signals with respect to the detection points FAn and FBn, respectively.

[0152] Thus, the focus/tilt detection system shown in FIG. 13, is arranged as a double-path system in which the projected beam reflected by wafer W is again reflected by wafer W, and can therefore have higher sensitivity for

detection of an error in the wafer W surface position in the Z-direction in comparison with a single-path system.

[0153] In this embodiment, a glass block (prism mirror 200) is provided at the extreme end of the focus/tilt detection system and is positioned such that a part of the glass block 200 is immersed in liquid LQ. As a result, the projected beam and the reflected beam do not pass any interface between liquid LQ and air, thus providing a stable beam path. Moreover, the effective length of the path in liquid LQ through which the projected beam or reflected beam travels (passes) is reduced by virtue of the prism mirror 200, thereby avoiding any reduction in accuracy due to temperature variation of liquid LQ at the time of Z-position measurement.

[0154] Modified examples of the structure of the wafer holder WH shown in FIGS. 1 and 5 are described with reference to FIGS. 14 and 15. FIG. 14 is a cross-sectional view of a wafer holder WH to be mounted in a projection exposure apparatus for performing immersion exposure. In this example, fine Z- drive units 220 such as piezoelectric elements are provided which can slightly move. The fine Z-drive units 220 are capable of moving an auxiliary plate HRS surrounding an attraction surface 113 on which wafer W is supported. The fine Z-drive units 220 move the auxiliary plate HRS in the Z-direction by a stroke of about several tens of micro-meters.

[0155] If the difference between the height of the

surface of wafer W placed on the attraction surface 113 of the wafer holder WH and the height of surface of the auxiliary plate HRS in the Z-direction is larger than an allowable difference, the Z-drive unit 220 is used to correct the height of surface of the auxiliary plate HRS so that the difference is reduced to a value smaller than the allowable value.

[0156] As mentioned above with reference to FIG. 5, the surface of the auxiliary plate HRS functions as an alternative detection surface for the focus detection points FA1 (or FA2), FC1 (or FC2), and FD1 (or FD2) located outside wafer W when shot area SA1 at the peripheral portion of wafer W is exposed. However, when inner shot area SA2 (see FIG. 5) of wafer W is exposed, these focus points are positioned on wafer W. Therefore, the focus detectors GDA1, GDA2, GDC1, GDC2, GDD1, and GDD2 having detection points each of which is not exclusively positioned on one of the surface of the auxiliary plate HRS and the surface of wafer W must accurately measure the Z-position on each of these surfaces. That is, it is necessary for the positions in the Z-direction of the surfaces of the auxiliary plate HRS and wafer W to be within the linear focus measuring range of the each focus detectors GDAn, GDCn and GDDn.

[0157] For example, if the linear focus measuring range of the focus detectors is ±10 micrometers, then the Z positional deviations of the surfaces of the auxiliary

plate HRS and wafer W are limited within the range of several micrometers. However, the thickness of wafers varies in a tolerance determined by the SEMI standard, and it is difficult to limit the thicknesses of all usable wafers within the range of several micro-meters.

[0158] Therefore, when wafer W is attracted to the wafer holder WH shown in FIG. 14 before exposure, the difference between the Z-position of a suitable portion of the wafer W surface (e.g., a central portion of a peripheral shot area) and the Z-position of the surface of the auxiliary plate HRS is measured by using one of the focus detection systems (GDL, GRD, GDC) before exposure. If the difference exceeds the allowable range (e.g., several micro-meters), the height of the auxiliary plate HRS is adjusted so that the difference is within the allowable range by controlling the fine Z-drive units 220 shown in FIG. 14. Since the wafer holder WH shown in FIG. 14 is filled with liquid LQ, the fine Z-drive units 220 are "waterproofed" to prevent the liquid from entering the units.

[0159] The construction shown in FIG. 15 is next described. FIG. 15 is a cross-sectional view of a modified example of the structure which includes a wafer holder WH and a ZL stage 30, and which is suitable for exposure of a wafer in air. The components corresponding to those shown in FIG. 14 are indicated by the same reference characters or numerals. Referring to FIG. 15, the wafer holder WH is constructed as a chuck on which only an attraction surface

113 for supporting wafer W is formed, and which is fixed on a ZL stage 30.

[0160] An auxiliary plate HRS is mounted on the ZL stage 30 with fine Z-drive units 220 interposed therebetween. Each of function points PV of three Z-actuators 32A, 32C, and 32B (32B not being seen in FIG. 15) for driving the ZL state 30 in the Z- direction and a tilting direction are set to points at a peripheral portion of the ZL stage 30 substantially at the same height as the wafer mount surface (attraction surface 113) of the wafer holder WH.

[0161] Also in the arrangement shown in FIG. 15, the height of the auxiliary plate HRS is adjusted to that of the upper surface of wafer W by using fine Z-drive units 220 in the same manner as shown in FIG. 14. The height of the height of the function points PV are set to the same level as the wafer surface. The structure of the ZL stage 30 and the Z-actuators 32 shown in FIG. 15 may also be applied to the aligner shown in FIG. 1. Also, the wafer holder WH of FIG. 14 may be mounted on the ZL stage 30 of FIG. 15 to thereby form a focusing and tilting stage suitable for immersion projection exposure apparatus or its method.

[0162] The present invention has been described with respect to applications to exposure apparatus. However, the above-described embodiments can be modified in various ways without departing from the scope of the present invention. For example, the focus detection systems GDL,

GDR, and GDC may include electrostatic capacity type gap sensors or air micrometer type gap sensors in a case of an aligner for performing projection exposure in air. Also, the present invention is applicable e.g. to any of the step-and-repeat type, step-and-scan type and "1X" scanning type projection aligners using, as exposure light, g-line (463 nm) or i-line (365 nm) from a mercury discharge lamp or pulse light (248 nm) from KrF excimer laser.

[0163] According to the present invention, precise focusing and tilt control at the exposure position can be realized while the working distance of the projection optical system mounted in the projection aligner is set to an extremely small value, so that correction of various aberrations and distortion correction in optical design of the projection optical system become easier and the transparent optical element positioned near the image plane, in particular, can be reduced in size.

[0164] Each of the focusing/tilt control systems in accordance with the above-described embodiments of the present invention is applicable to a certain type of projection exposure apparatus. However, the present invention is also applicable to focus/tilt detection systems for beam processing (manufacturing) apparatuses, writing apparatuses, inspection apparatuses and the like and is not limited to semiconductor fabrication. These beam processing apparatuses, writing apparatuses and inspection apparatuses are provided with an optical or

electrooptical objective lens system. The present invention is applicable to the optical or electrooptical objective lens system, as a focus detection system for detecting a focus on a substrate, specimen or workpiece.

[0165] FIG. 16 shows the construction of a focus detection system applied to an objective optical system of an apparatus for processing a workpiece with a laser or electron beam or for writing a pattern on a workpiece, and FIG. 17 shows a planar layout of detection points of the focus detection system shown in FIG. 16.

[0166] Referring to FIG. 16, a processing or writing beam LBW is deflected unidimentionally or two-dimensionally by a scanning mirror 300 and travels via a lens system 301, a fixed mirror 302 and a lens system 303 to be incident upon a beam splitter 304. The beam LBW is reflected by the beam splitter 304 to be incident upon a high-resolution objective lens system 305 having a small working distance. The beam LBW is condensed into a small spot having a predetermined shape (e.g., a variable rectangular shape) on a workpiece WP by the objective lens system 305.

[0167] The workpiece WP is attracted to and fixed on the same holder WH as that shown in FIG. 14 or 15. An auxiliary plate HRS is attached integrally to the holder WH around the workpiece WP. The holder WH is fixed on an unillustrated XYZ- stage to be moved two-dimensionally in a horizontal direction and in a direction perpendicular to paper surface as viewed in FIG. 16. The holder WH is also

moved slightly in the vertical direction (Z-direction) for enabling the focusing.

[0168] The apparatus shown in FIG. 16 is also provided with an optical fiber 310 for emitting illumination light for observation, alignment or aiming; a beam splitter 311 and a lens system 312 for leading the illumination light to the above-mentioned beam splitter 304; and a light receiving device (e.g. photomultiplier, image pickup tube, CCD or the like) 314. The light receiving device 314 is configure to photoelectrically detect reflected light, scattered and diffracted light or the like obtained from the workpiece WP through the objective lens system 305.

[0169] Pre-reading focus detection systems GDL and GDR and a processing position focus detection system GDC are provided around the objective lens system 305. FIG. 17 shows a field 305A of the objective lens system 305 and a planar layout of detection points of the focus detection systems disposed around the field 305A. For convenience, the center of the field 305A is set at the origin of an XY coordinate system. A rectangular area in the field 305A indicates the range through which the spot of the beam LBW scans by the deflection of the beam LBW caused by the scanning mirror 300.

[0170] Focus detectors GDA1, GDBn, and GDA2 on the left-hand side of the field 305A of the objective lens system are disposed so that detection points FA1, FB1, FB2, FB3, and FA2 is set in a row parallel to the Y-axis. Also,

focus detectors GDD1, GDEn, and GDD2 on the right-hand side of the field 305A are disposed so that detection points FD1, FE1, FE2, FE3, and FD2 is set in a row parallel to the Y-axis.

[0171] On the other hand, a focus detector GDC1 provided above the field 305A is set so that three detection points FD1a, FD1b, and FD1c are placed on a line passing the two detection point FA1 and FD1 and parallel to the X-axis; on the other hand, a focus detector GDC2 provided below the field 305A is set so that three detection points FD2a, FD2b, and FD2c are placed on a line passing the two detection point FA2 and FD2 and parallel to the X-axis. In this embodiment, a set of the focus detectors GDA1, GDBn and GDA2 and a set of the focus detectors GDD1, GDEn and GDD2 are selected as the focus pre-reading function while the workpiece WP moves in the X-direction. On the other hand, the focus pre-reading function is achieved by selecting a set of the focus detectors GDA1, GDC1 and GDD1 and a set of the focus detectors GDA2, GDC2 and GDD2 while the workpiece WP moves in the Y-direction. This embodiment is arranged so that the detection points of the focus detectors GDBN, GDC1, GDC2, and GDEn can be changed for enabling detection of a focus of the processing position. For example, when the workpiece WP is moved in the X direction from the left-hand side to the right-hand side of FIG. 16, one of three pairs of detection points FD1a and FD2a, detection points FD1b and FD2b, and detection points

FD1c and FD2c may be selected for focus detection of the processing position while the detection points FA1, FB1, FB2, FB3, and FA2 are being used for pre-reading.

[0172] This construction is intended to achieve an effect described below. That is, the position of the spot of the processing or drawing light beam LBW changes in the scanning range 305B. Therefore, when for example, the spot of the light beam LBW is positioned at the leftmost end of the scanning range 305B as shown in FIG. 17, the two detection points FD1a and FD2a are selected for processing position focus detection. When the spot of the light beam LBW is positioned at the rightmost end of the scanning range 305B, the two detection points FD1c and FD2c are selected for processing position focus detection.

[0173] In this method, the reproducibility and accuracy of focus control or tilt control are improved. The holder WH shown in FIG. 16 is slightly moved in the focusing (Z) direction and in a tiling directions on the XY stage. As a drive system and a control system for performing this movement, those shown in FIG. 4 can be used without being substantially modified.

[0174] As described above, the focus detection system shown in FIGS. 16 and 17 is arranged to enable the pre-reading detection of the focus in each of the directions of the two-dimensional movement of workpiece WP and to enable the focus detection point for the processing position to be selected according to the position of the beam spot in the

field 305. As a result, even a peripheral portion of workpiece WP is precisely processed (imaged) in an accurately focused state or pattern imaging can be performed thereon in such a state.

[0175] An inspection apparatus to which the focus/tilt detection system of the present invention is applicable is described briefly with reference to FIG. 18. Fig. 18 shows an example of an apparatus which optically inspects defects in patterns drawn on a mask or reticle for photolithography or defects in circuit patterns of a semiconductor device or liquid crystal display device formed on a substrate.

[0176] In recent years, techniques for examining the quality of an inspected pattern (pattern-to-be-inspected, inspection objective pattern) formed on a specimen (substrate) and checking the presence or absence of extraneous materials or particles and damage, by enlarging the inspected pattern through an objective optical system, by forming an enlarged image of the pattern by a CCD camera or the like and by analyzing an image signal obtained from such an image, have been constructively introduced into this kind of inspection apparatus.

[0177] In such a case, it is important to improve the accuracy such that an accurately enlarged image of the inspected pattern is obtained. An objective lens system having high resolution and a large field size and capable of forming an image with minimized aberrations and distortion is therefore required. Such an objective lens

system naturally has a small working distance and is ordinarily designed as a through the lens (TTL) type such that focus detection is made through the objective lens system. However, a TTL optical focus detection system entails a problem of limiting the detection sensitivity (the amount of change in detection signal with respect to an error in focusing a specimen) because of a restriction due to the numerical aperture (NA) of the objective lens system.

[0178] If a TTL focus detection system is formed so as to use light having a wavelength different from that of illumination light for inspection, then aberration correction must be taken into consideration with respect to the wavelength ranges of inspection illumination light and focus detection illumination light in the optical design of the objective lens system. In such a case, the lens cannot always be designed optimally with respect to inspection illumination light.

[0179] Then, as shown in FIG. 18, a plurality of sets of focus detection systems GDC, GDL, and GDR are provided around an objective lens 330 such that inspection in the same manner as those shown in FIGS. 16 and 17 is possible. A specimen WP to be inspected is e.g. a mask having a pattern Pa formed on its lower surface. The specimen WP is supported at its peripheral end on a frame-like two-dimensionally-movable stage 331 having an opening. The objective lens 330 is mounted in an upward-facing state on

a base member 332 which guides movement of the stage 331. An enlarged image of a local area in pattern Pa is imaged on an imaging plane of an image pickup device 336 through a beam splitter 334 and a lens system 35.

[0180] On the opposite side of the specimen WP, a condenser lens 338 of an illumination optical system is disposed to be coaxial with the axis AX of the objective lens 330. Illumination light from an optical fiber 340 travels through a condenser lens 341, an illumination field stop 342 and a lens system 343 to be incident upon the condenser lens 338, thereby irradiating an area on the specimen WP corresponding to the field of the objective 330 with a uniform illuminance.

[0181] In the above-described arrangement, the focus detection systems GDC, GDL and GDR are mounted on the base member 332 together with the objective 330 so as to upwardly face the pattern Pa. A plurality of focus detectors (a plurality of detection points) are provided in the focus detection systems GDL and GDR capable of performing the pre-reading; on the other hand, at least one pair of focus detectors is provided in the focus detection system GDC which is capable of performing detection at the inspection position.

[0182] Also in the focus detection system shown in FIG. 18, the specimen WP on the stage 331 may be moved vertically along the optical axis AX or tilted on the basis of focus position information detected by the focus

detectors by using a control circuit such as that shown in FIG. 4. In the inspection apparatus shown in FIG. 18, however, only an effect of obtaining a high-quality enlarged image of the pattern Pa imaged by the image pickup device 36 may suffice. Therefore, a focus adjuster 352A or 352B for slightly moving the objective lens 330 or the lens system 335 along the optical axis AX may be provided, instead of the means for vertically moving the specimen WP.

[0183] An inspection apparatus in which a mask pattern Pa provided as a specimen WP is positioned so as to face downward has been described by way of example with reference to FIG. 18. Needless to say, this embodiment can be directly applied to an inspection apparatus in which pattern Pa faces upward, while the objective lens faces downward. In the apparatus shown in FIG. 18, a transmitted image of pattern Pa is inspected by a coaxial transmission illumination system.

[0184] However, the illumination system may be changed so that coaxial reflection illumination light is introduced through the beam splitter 334 in the direction of arrow 350 in FIG. 18. In such a case, the enlarged image received by the image pickup device 336 is formed by imaging reflected light from the pattern Pa.

[0185] Further, another method may be used in which a spatial filter provided with a transmission portion having a desired shape is removably placed at the position of a Fourier transform plane formed in the optical path of the

illumination optical system or in the imaging optical system. With this, a bright field image or a dark field image of pattern Pa can be selectively imaged on the image pickup device 336.

[0186] This disclosure is illustrative and not limiting; further modifications will be apparent to one of ordinary skill in the art in light of this disclosure, and are intended to fall within the scope of the appended claims.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[FIG. 1] FIG. 1 is a diagram showing a scanning projection exposure apparatus (aligner) in a first embodiment of the present invention;

[FIG. 2] FIG. 2 is a schematic perspective view explaining a scanning exposure sequence;

[FIG. 3] FIG. 3 is a schematic perspective view of the disposition (arrangement) of a focus detection system provided in the vicinity of an end of the projection lens system shown in FIG. 1;

[FIG. 4] FIG. 4 is a circuit block diagram of a circuit arrangement (construction) in the AF control unit shown in FIG. 1;

[FIG. 5] FIG. 5 is a plan view of the positional relationship between a projection field and detection areas of focus sensors on the wafer in the apparatus shown in FIG. 1;

[FIG. 6] FIG. 6A is a diagram of the focusing and tilting operation of the apparatus shown in FIG. 1, FIG. 6B

is a diagram of the focusing and tilting operation of the apparatus shown in FIG. 1, FIG. 6C is a diagram of the focusing and tilting operation of the apparatus shown in FIG. 1, and FIG. 6D is a diagram of the focusing and tilting operation of the apparatus shown in FIG. 1;

[FIG. 7] FIG. 7 is a plan view of a layout of detection areas of a focus/tilt detection system in a second embodiment of the present invention;

[FIG. 8] FIG. 8 is a side view of a layout of a modified example of the focus/tilt detection system shown in FIG. 7;

[FIG. 9] FIG. 9 is a schematic diagram in a third embodiment of the present invention in which the invention is applied to a scanning exposure apparatus (scanning aligner);

[FIG. 10] FIG. 10 is a perspective view of a vertical carriage applied to the scanning aligner shown in FIG. 9;

[FIG. 11] FIG. 11 is a perspective view of a projection optical system and a focus detection system provided in the projection aligner shown in FIG. 9;

[FIG. 12] FIG. 12 is a cross-sectional view in a fourth embodiment of the present invention in the construction of which the invention is applied to an immersion projection exposure apparatus;

[FIG. 13] FIG. 13 is a diagram showing an example of an optical path layout of a focus/tilt detection system suitable for the immersion projection exposure apparatus;

[FIG. 14] FIG. 14 is a cross-sectional view of a modified example of the wafer holder;

[FIG. 15] FIG. 15 is a cross-sectional view of a modified example of the wafer holder;

[FIG. 16] FIG. 16 is a diagram showing an example of a manufacturing or imaging or writing apparatus to which the focus detection sensor of the present invention is applied;

[FIG. 17} FIG. 17 is a plan view showing an exemplary layout of the focus detection system applied to the apparatus shown in FIG. 16; and

[FIG. 18] FIG. 18 is a diagram schematically showing the construction of an exemplary inspection apparatus to which the focus/tilt detection system of the present invention is applied.

[EXPLANATION OF REFERENCE NUMERALS]

10 illumination system

11 mirror

12 condenser lens system

13 column structure

14 reticle stage

15 motor

16 moving mirror

17 laser interferometer system

20 reticle stage controller

25 main controller

30 ZL stage

31 moving mirror

32A Z-actuator

32B Z-actuator

32C Z-actuator

33 laser interferometer

34 XY stage

35 wafer stage controller

36 drive motor

52 position monitor circuit

54 first calculator

56 second calculation and memory circuit

58 third calculation and memory circuit

80A illumination optical system

80B light receiving device

81A multi-slit plate

81B receiving slit plate

82A lens system

82B lens system

83A reflecting mirror

83B reflecting mirror

84A objective lens

84B objective lens

85A prism

85B prism

100 carriage

112 tubing

113 attraction surface

120A fixed base

121A side frame portion

121B side frame portion

122 illumination unit

123 guide base portion

123A guide rail

123B guide rail

125A mask-side carriage portion

125B plate-side carriage portion

126A mask table A

126B plate stage

200 prism mirror

200a reflecting surface

200b reflecting surface

200c flat surface

200d flat surface

202 light source

205 multi-slit plate

207 beam splitter

209 objective lens

211 objective lens

213 reflecting mirror

215 photoelectric detector

220 Z-drive unit

300 scanning mirror

301 lens system

302 fixed mirror

303 lens system

304 beam splitter

305 objective lens system

310 optical fiber

311 beam splitter

312 lens system

314 light receiving device

330 objective lens

331 stage

332 base member

335 lens system

334 beam splitter

336 image pickup device

341 condenser lens

342 illumination field stop

343 lens system

338 condenser lens

352A adjuster

352B adjuster

AX optical axis

Cp image field

Ep exit pupil

FA1 detection point

FB1 detection point

FB2 detection point

FB3 detection point

FA2 detection point

FC1 detection point

FC2 detection point

GDL focus detection system

GDR focus detection system

GDA1 detector

GDA2 detector

GDB1 detector

GDB2 detector

GDB3 detector

GDD1 detector

GDD2 detector

GDE1 detector

GDE2 detector

GDE3 detector

GDC focus detection system

GDC1 detector

GDC2 detector

HRS auxiliary plate portion

IA pulse illumination light

IL illumination light

ILF illumination light

LGa fore-group lens system

LGb rear-group lens system

LLa straight line

LLb straight line

LLc extension line

LE1 positive lens element

LQ liquid

LB	wall portion
LK	light
LBW	beam
M	mask
MR1	concave mirror
MR2	concave mirror
MR2a	concave mirror
MR2b	concave mirror
NT	notch
P	plate
Pa	circuit pattern area
Pe	flat lower surface
PL	projection lens system
PM1	prism mirror
PM2	prism mirror
PM3	prism mirror
PM4	prism mirror
PV	function point
R	reticle
RSf	imaging ray
SAa	shot area
SAb	shot area
SB	shield band
SI	projected image
SLf	imaging ray
W	wafer
WH	wafer holder

[ABSTRACT]

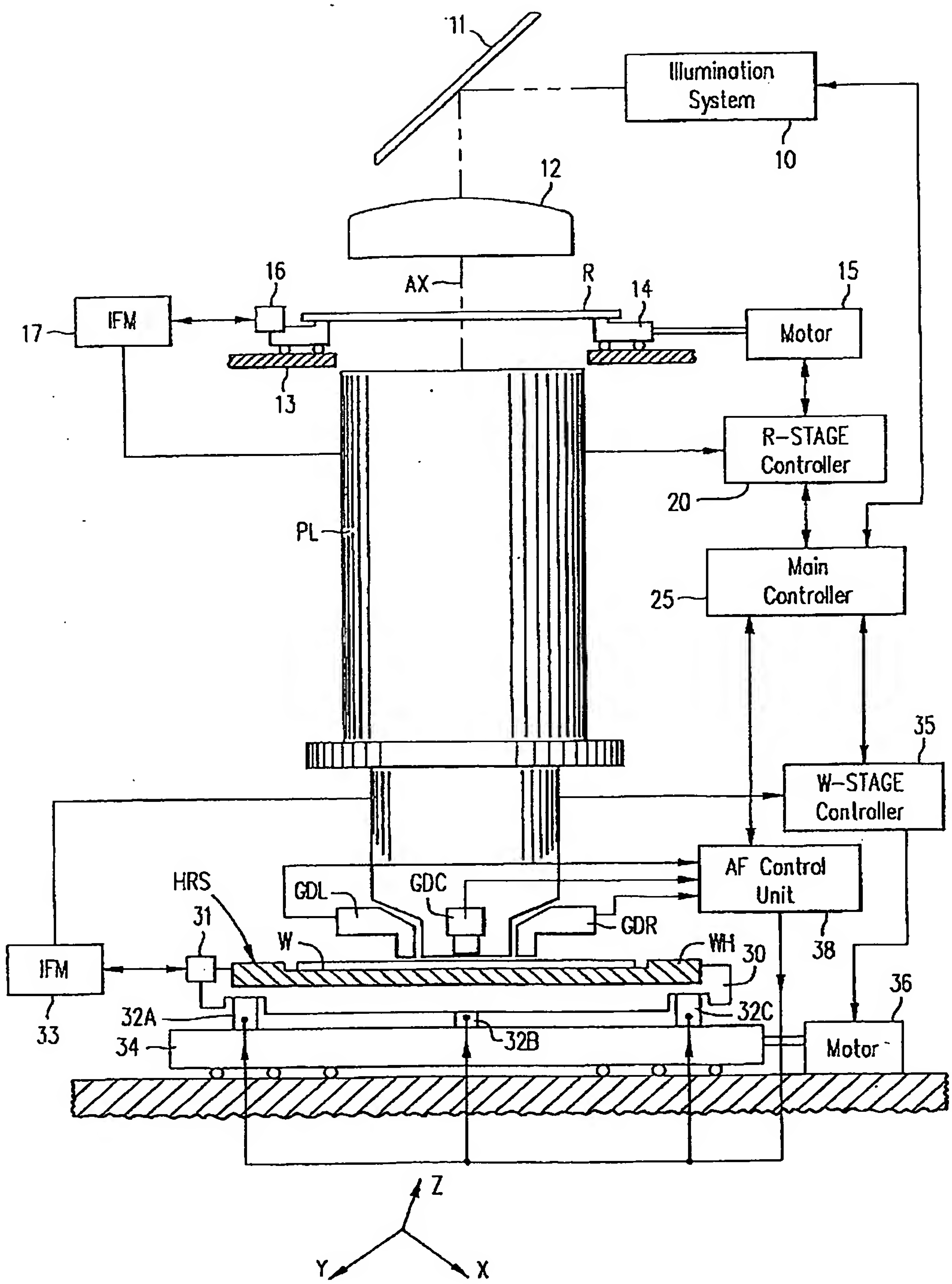
[PROBLEM TO BE SOLVED]

To perform high-precision focusing control and high-precision tilt control even if a projection optical system reducing the working distance in comparison with the conventional projection optical system is incorporated.

[MEANS TO SOLVE PROBLEMS]

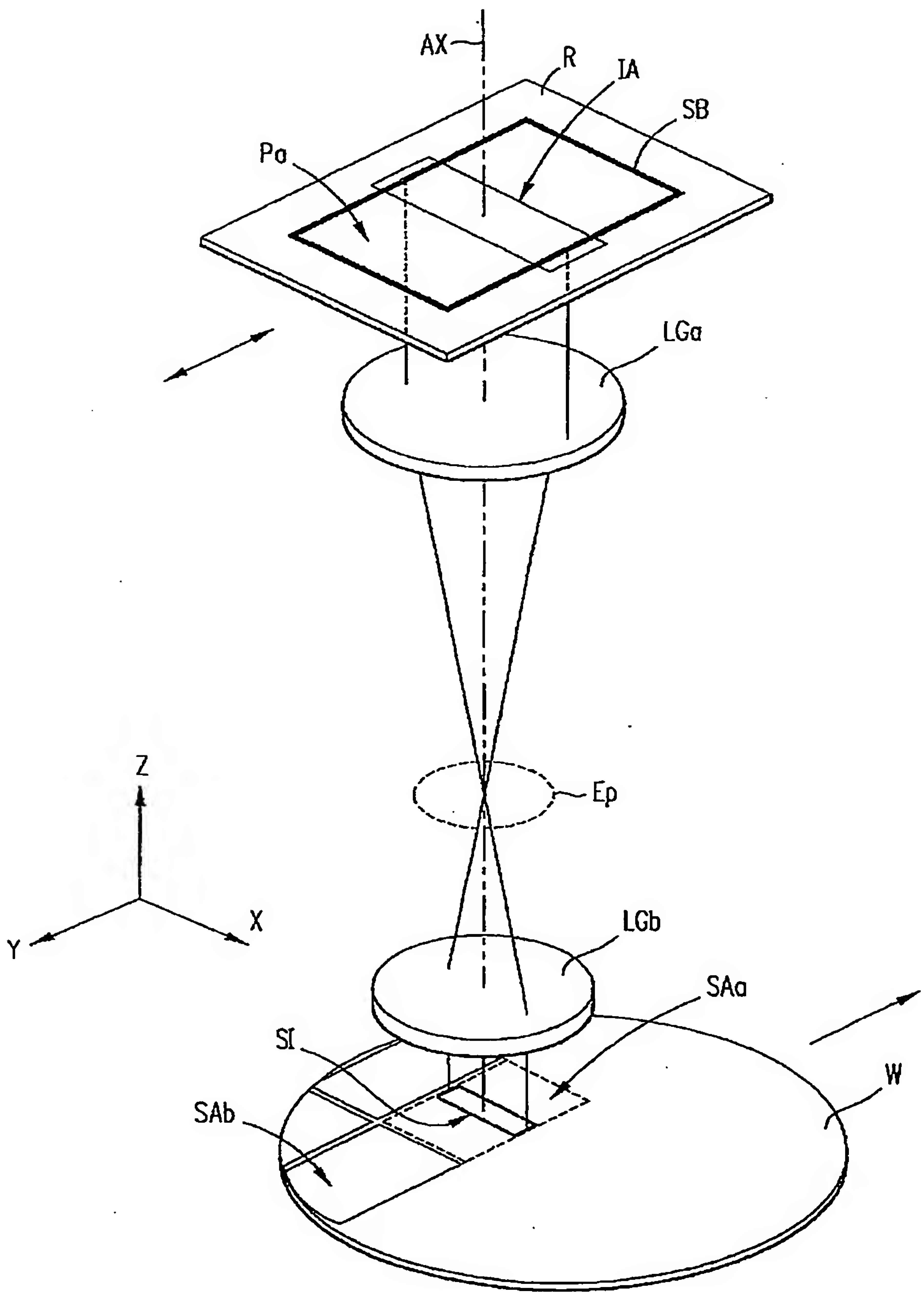
A focusing apparatus has a first detection system having a detection area at a first position, a second detection system having a detection area at a second position, and a third detection system having a detection area at a third position. The first, second and third detection points are located outside the field of the objective optical system, and are spaced apart from each other. A deviation between a first focus position and a target focus position is calculated and a second focus position is temporarily stored at the time of detection made by the first detection system. A controller performs focusing control, on the basis of the calculated deviation, the stored second focus position and a third focus position, when an area on the workpiece corresponding to the detection area of the first detection system is positioned in the field of the objective optical system by relative movement of the workpiece and the objective optical system.

【Fig. 1】

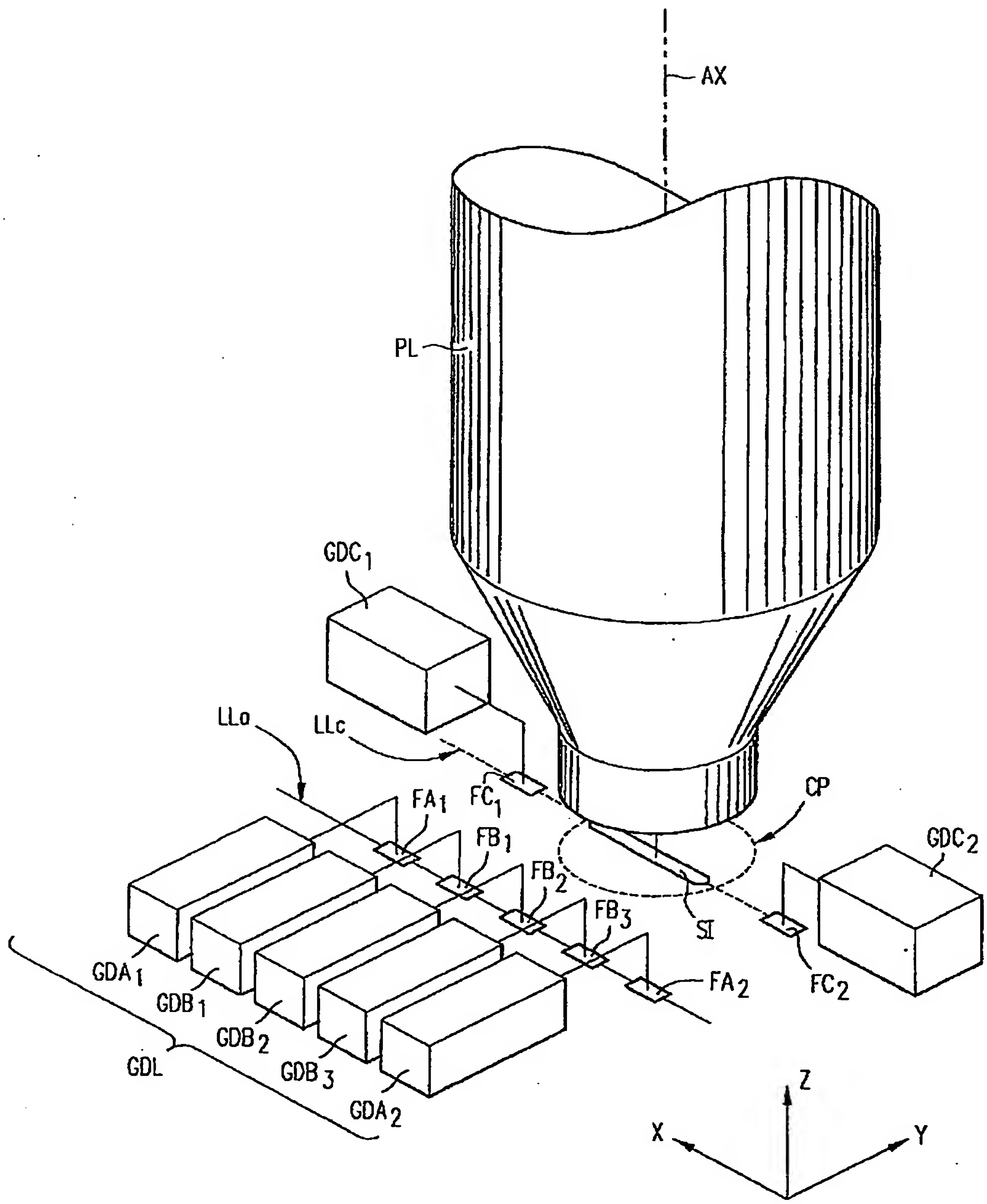


11
Illumination System
10
12
16
AX
R
14
15
17
IFM
Motor
13
R-STAGE Controller
20
PL
Main Controller
25
35
W-STAGE Controller
AF Control Unit
HRS
GDL
GDC
GDR
31
W
WH
30
38
IFM
33
32A
32B
32C
36
34
Motor
Z
Y
X

【Fig. 2】

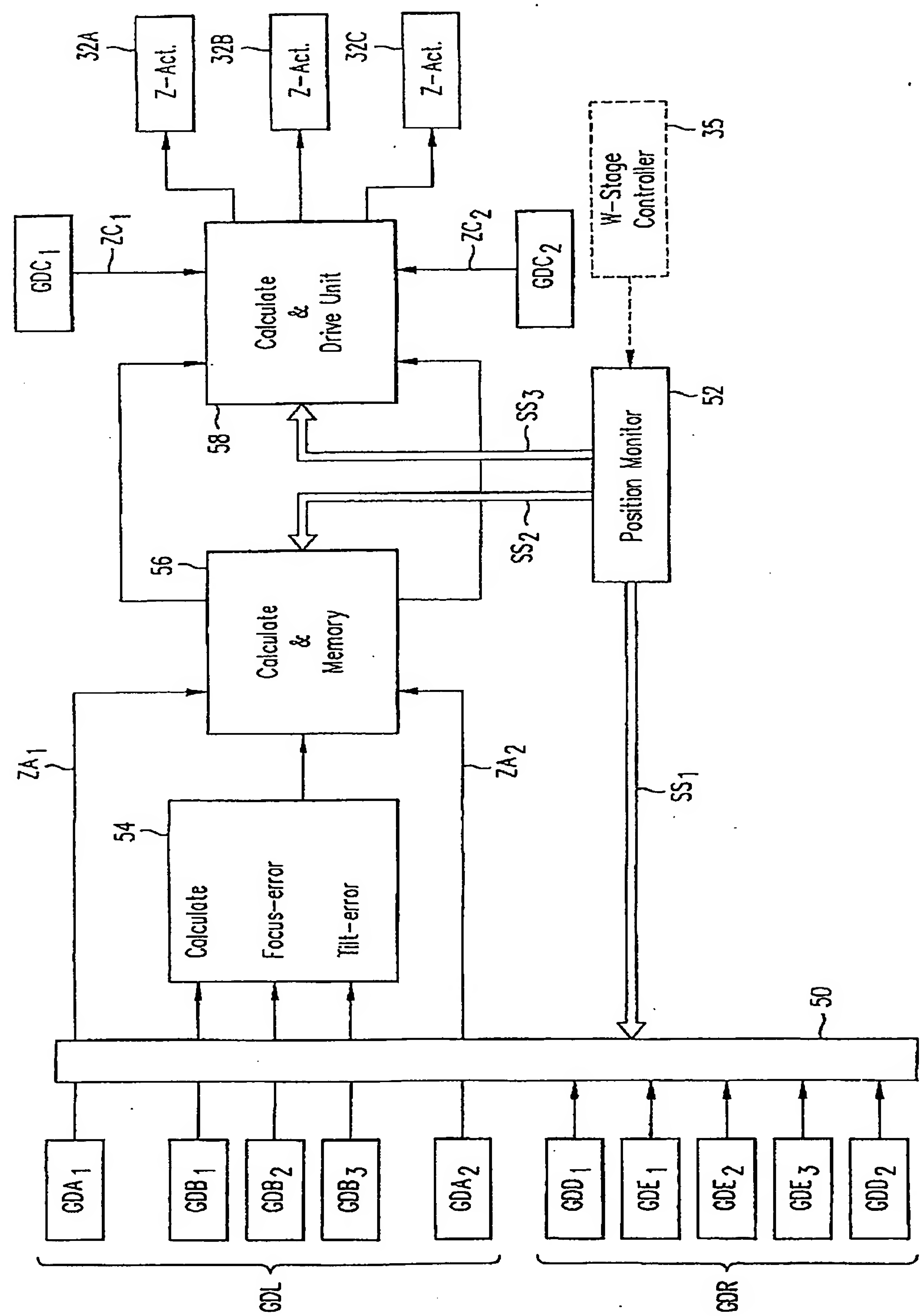


【Fig. 3】



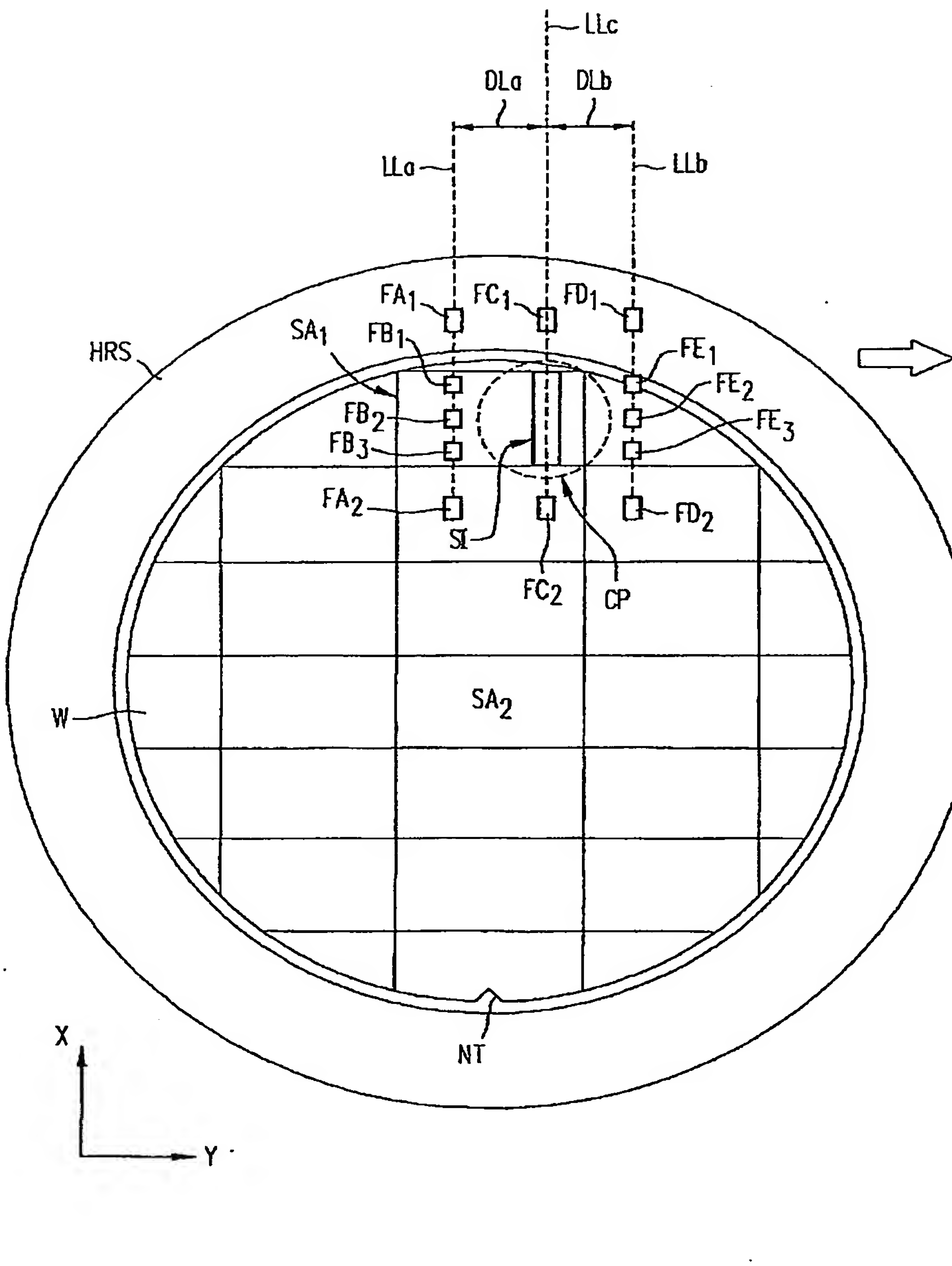
AX
PL
GDC1
LLa
LLc
FC1
FA1
FB1
FB2
FB3
FA2
CP
GDC2
SI
FC2
GDA1
GDB1
GDB2
GDB3
GDA2
GDL
Z
X
Y

【Fig. 4】



Z-Act.
Z-Act.
Z-Act.
32A
32B
32C
GDC1
ZC1
GDC2
ZC2
Calculate & Drive Unit
58
W-Stage Controller
35
Position Monitor
52
SS3
SS2
SS1
Calculate & Memory
56
ZA1
ZA2
Calculate Focus-error Tilt-error
54
50
GDA1
GDB1
GDB2
GDB3
GDA2
GDD1
GDE1
GDE2
GDE3
GDD2
GDL
GDR

【Fig. 5】



LLc
DLa
DLb
LLa
LLb
FA1
FC1
FD1
SA1
FB1
FE1
HRS
FE2
FB2
FE3
FB3
FA2
FD2
SI
FC2
CP
SA2
W
NT
X
Y

【Fig. 6】

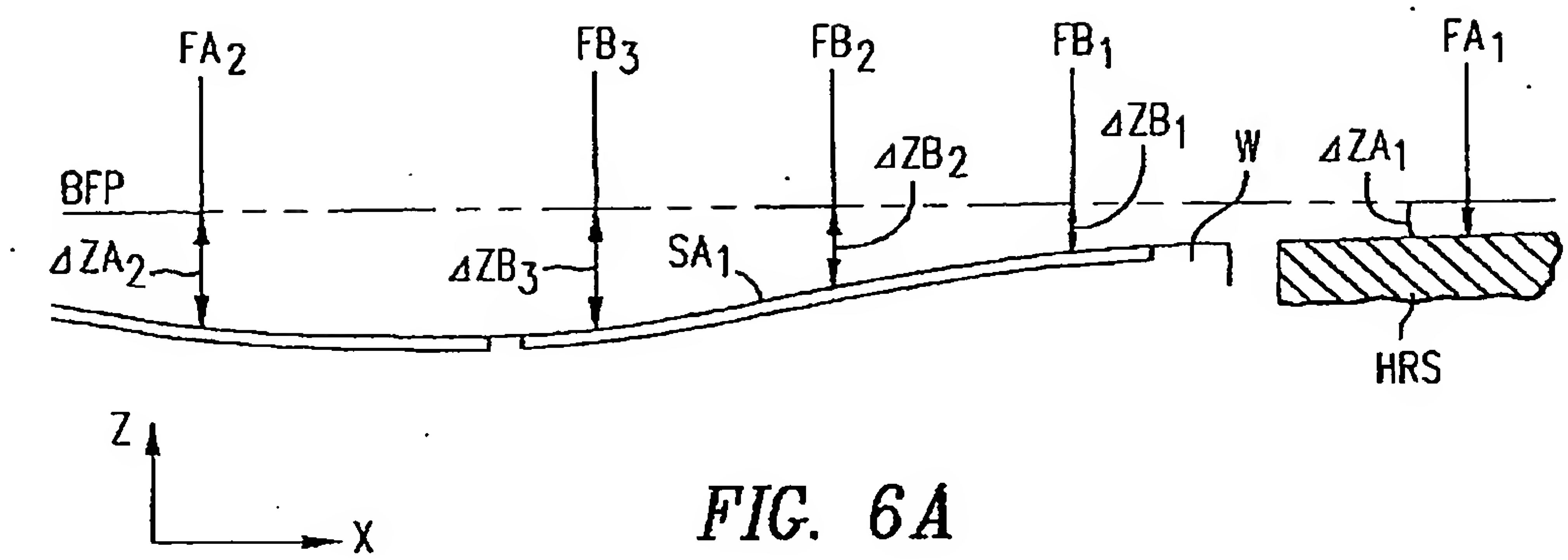


FIG. 6A

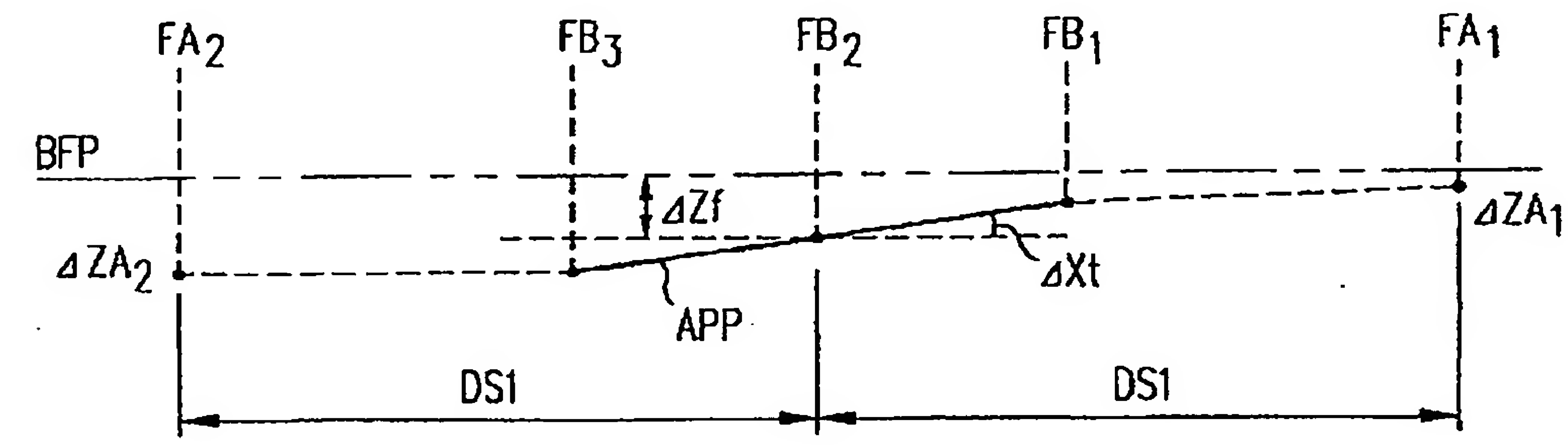


FIG. 6B

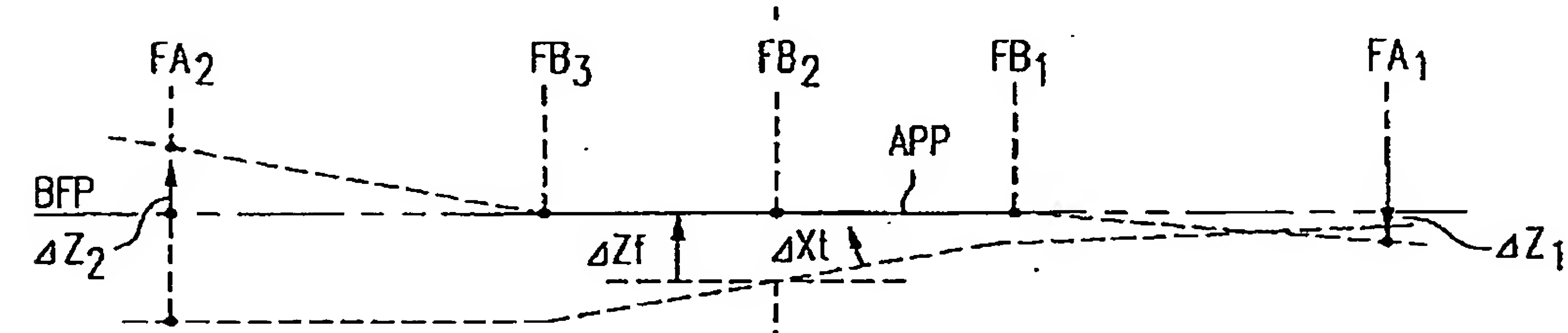


FIG. 6C

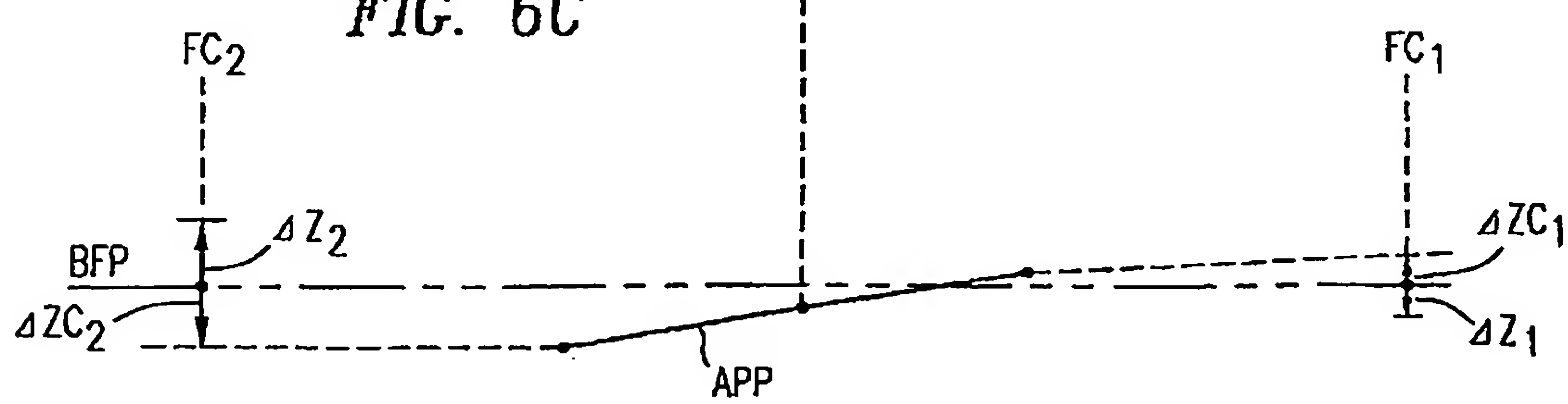
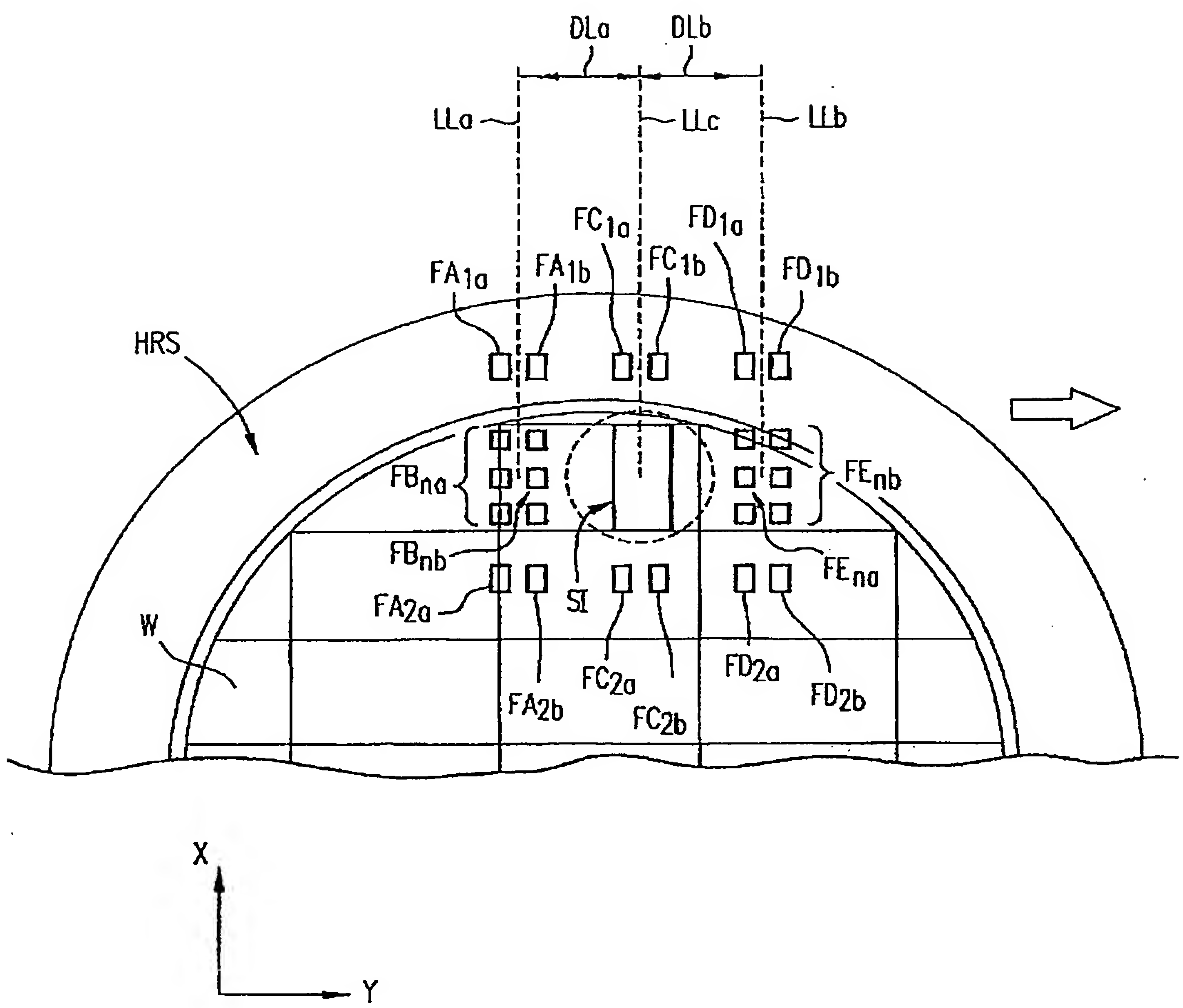


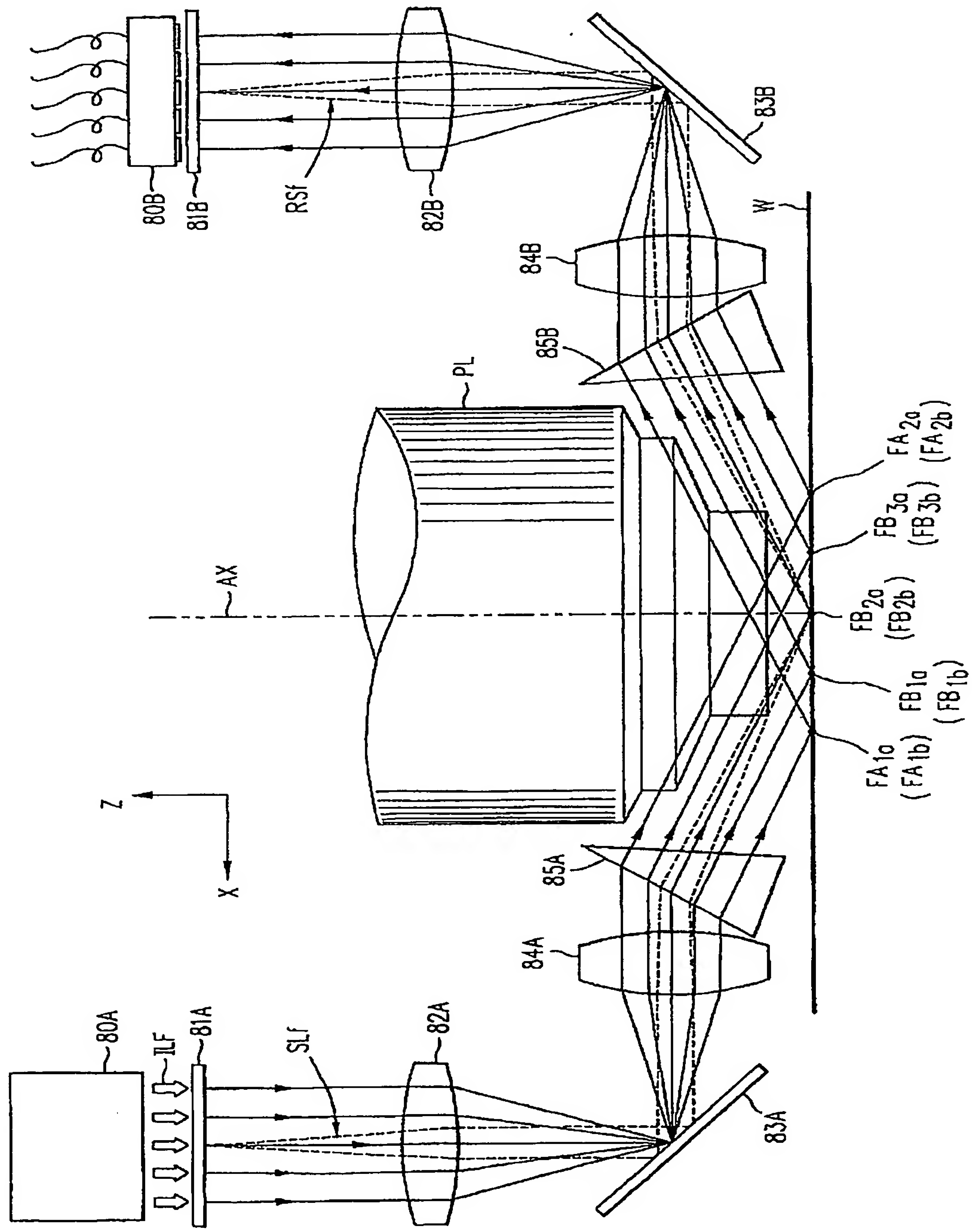
FIG. 6D

【Fig. 7】

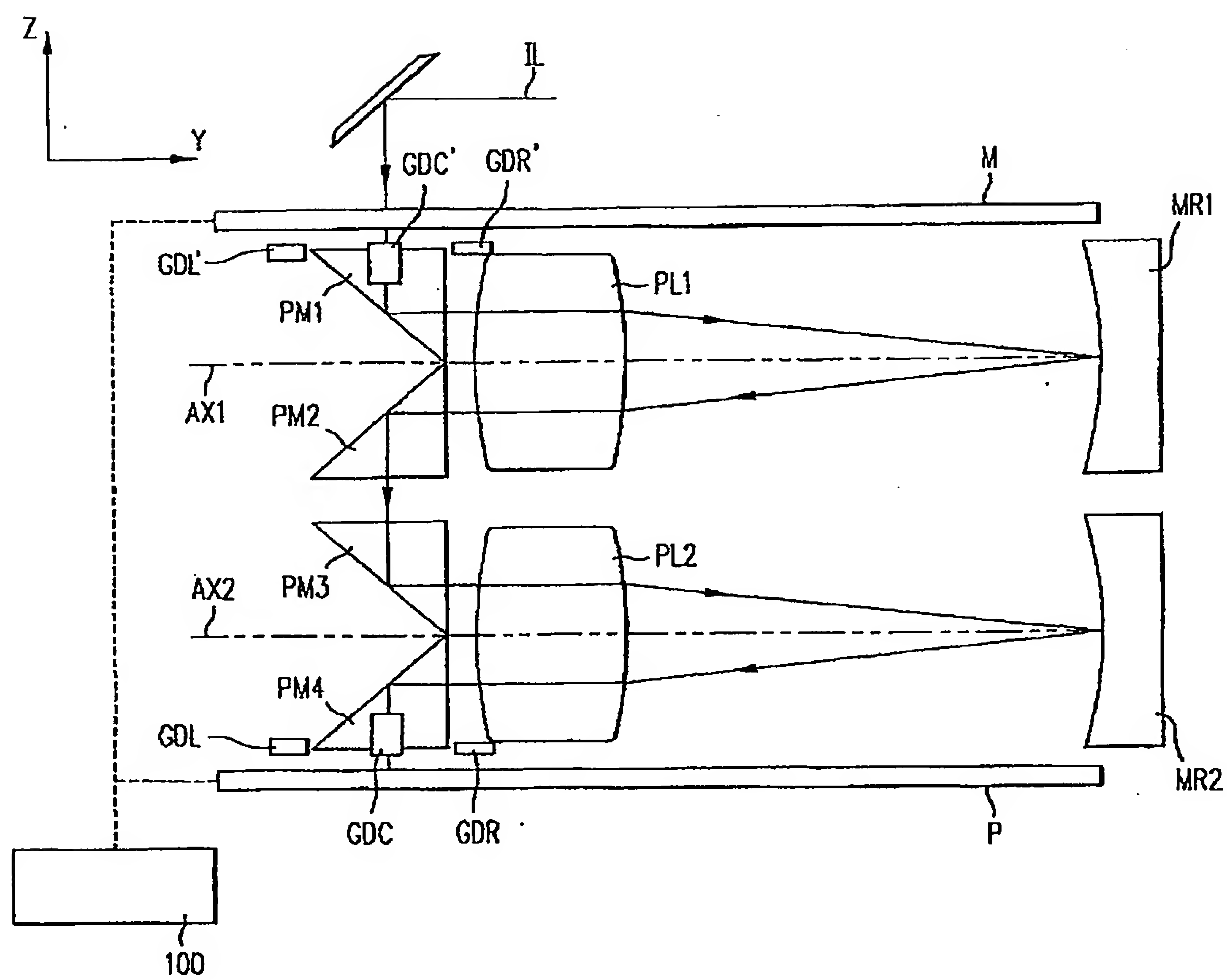


DLa
DLb
LLa
LLc
LLb
FC1a
FD1a
FA1a
FA1b
FC1b
FD1b
HRS
FBna
FEnb
FBnb
FEna
FA2a
SI
W
FC2a
FD2a
FD2b
FA2b
FC2b
X
Y

【Fig. 8】

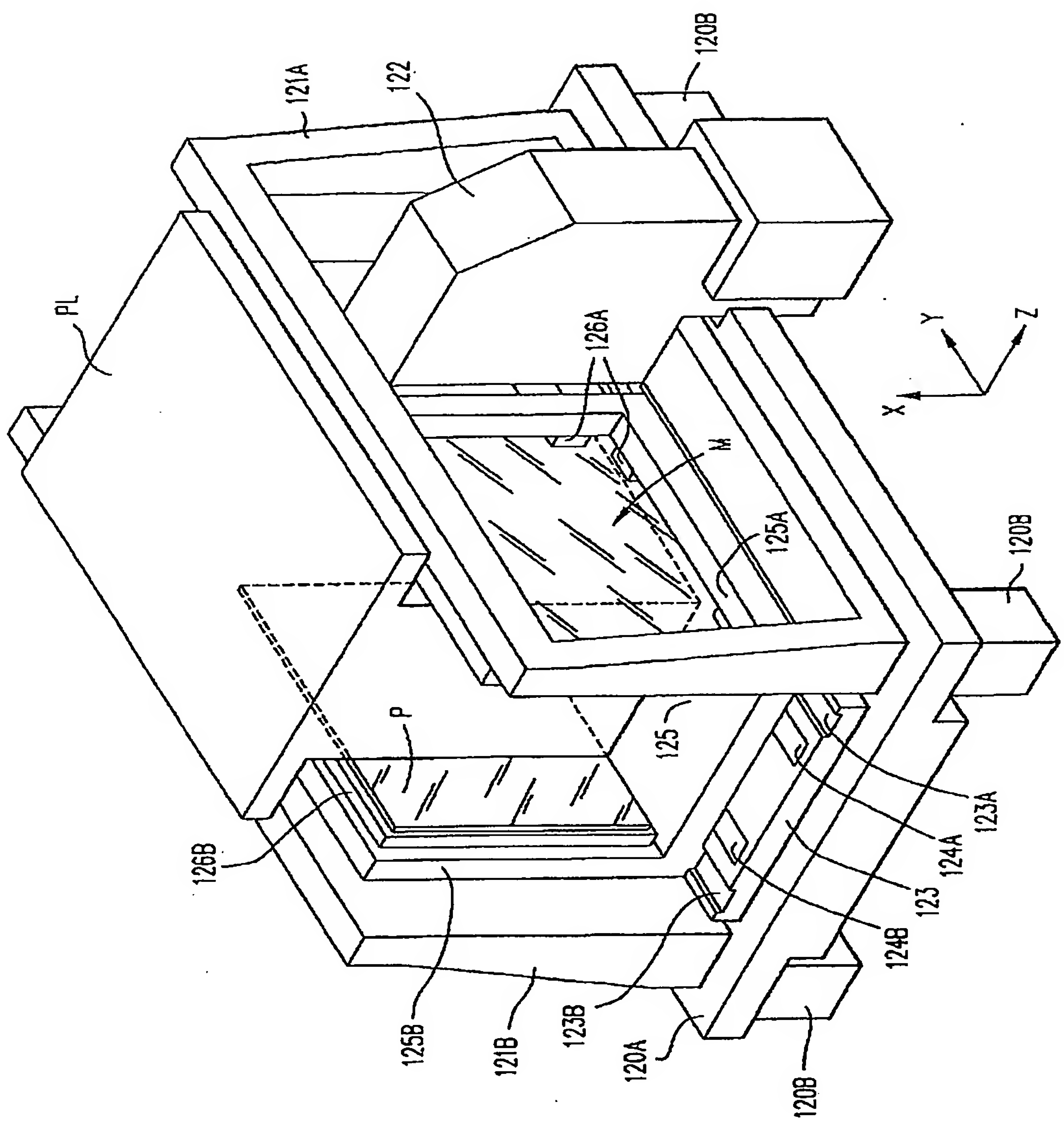

80A
ILF
81A
SLf
82A
83A
84A
85A
Z
X
PL
AX
85B
84B
W
83B
82B
RSf
81B
80B
FA1a
(FA1b)
FB1a
(FB1b)
FB2a
(FB2b)
FB3a
(FB3b)
FA2a
(FA2b)

【Fig. 9】



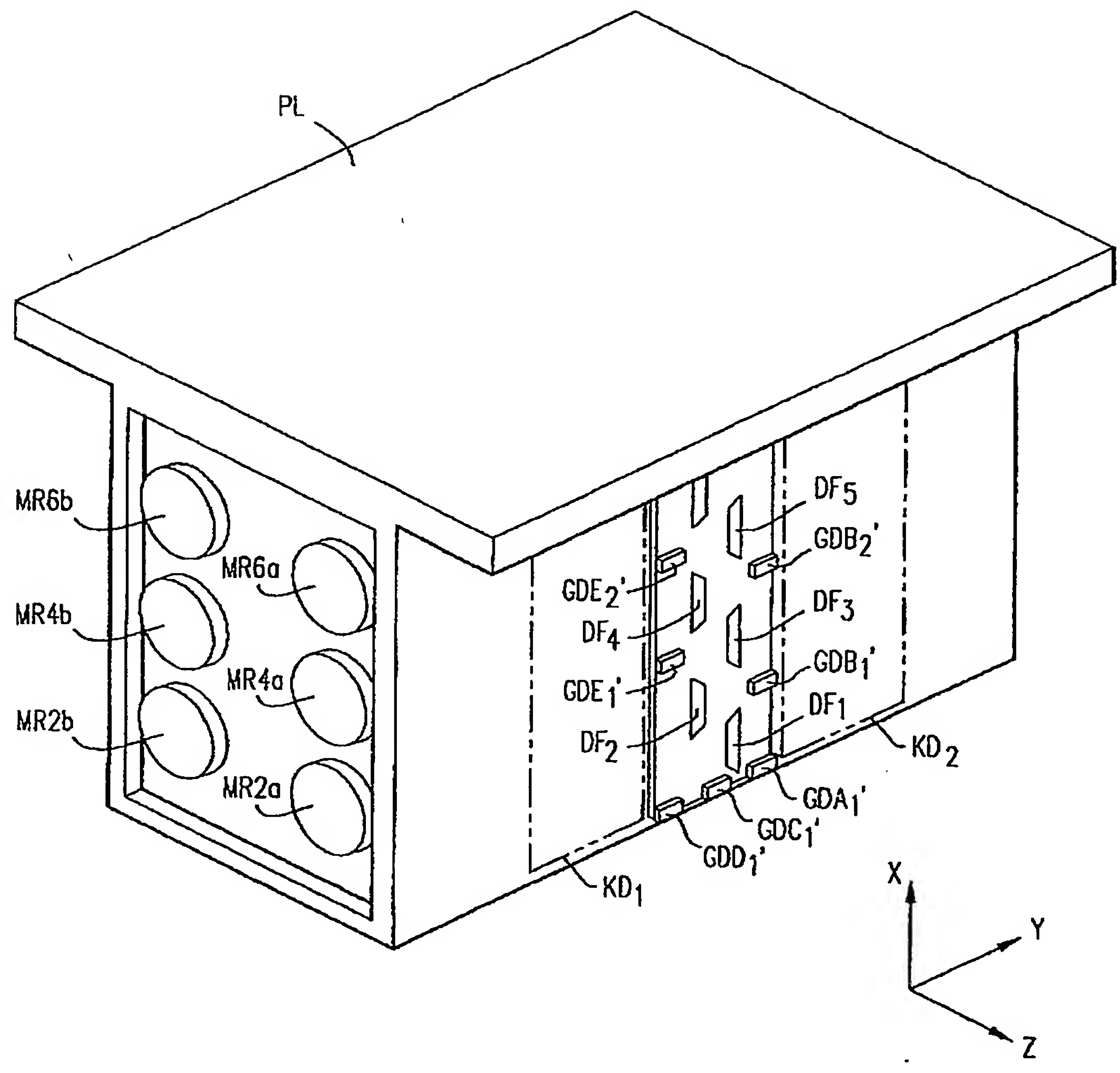
Z
Y
IL
GDC'
GDR'
M
MR1
GDL'
PL1
PM1
AX1
PM2
PL2
AX2
PM3
PM4
GDL
MR2
GDC
GDR
P
100

【Fig. 10】



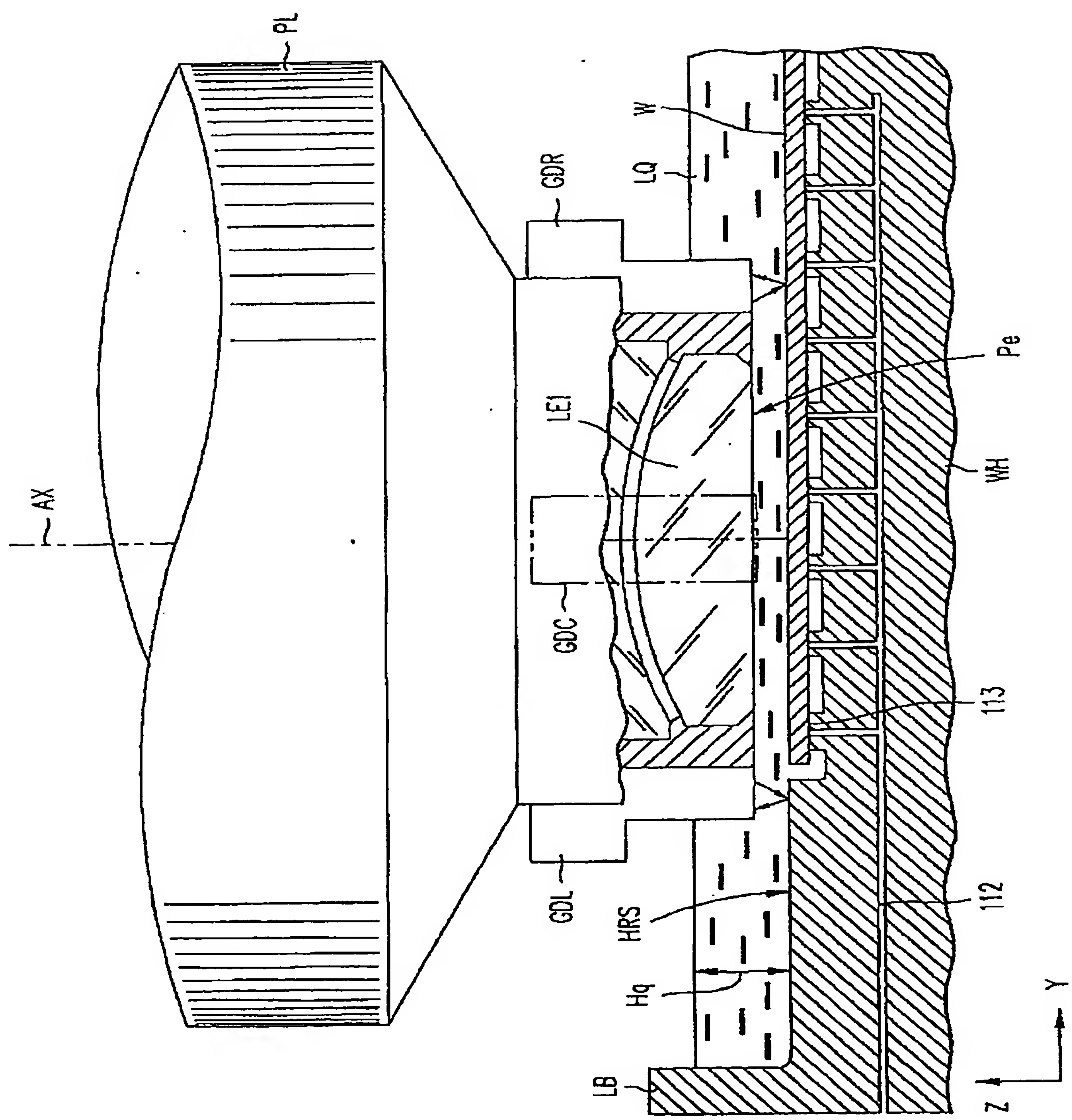
121A
122
120B
PL
126A
Y
Z
X
M
125A
120B
P
126B
125
123A
124A
123
124B
125B
121B
123B
120A
120B

【Fig. 11】

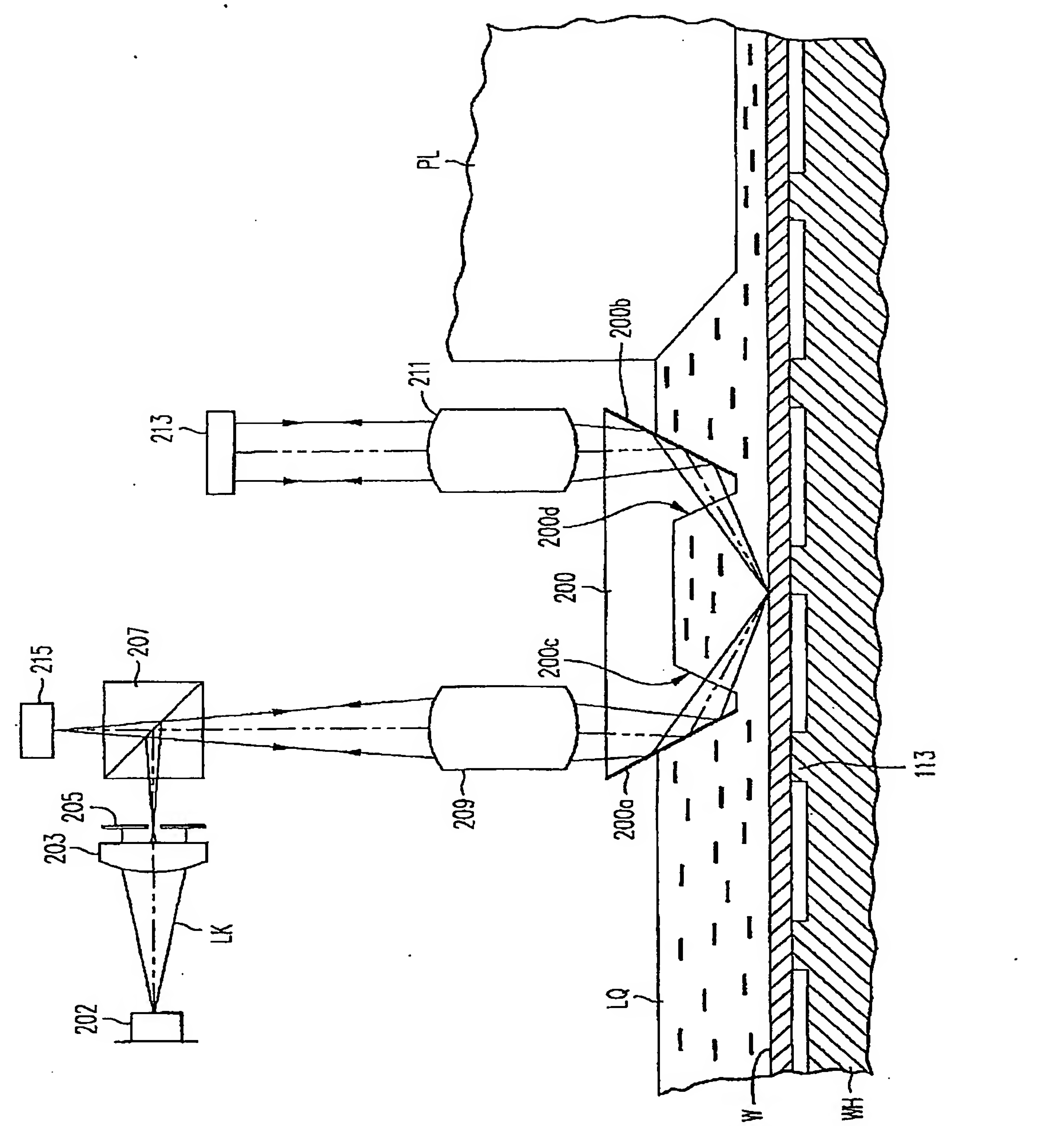


PL
MR6b
MR6a
MR4b
MR4a
MR2b
MR2a
DF5
GDB2'
GDE2'
DF3
DF4
GDE1'
GDB1'
DF1
DF2
KD2
GDA1'
GDC1'
GDD1'
KD1
X
Y
Z

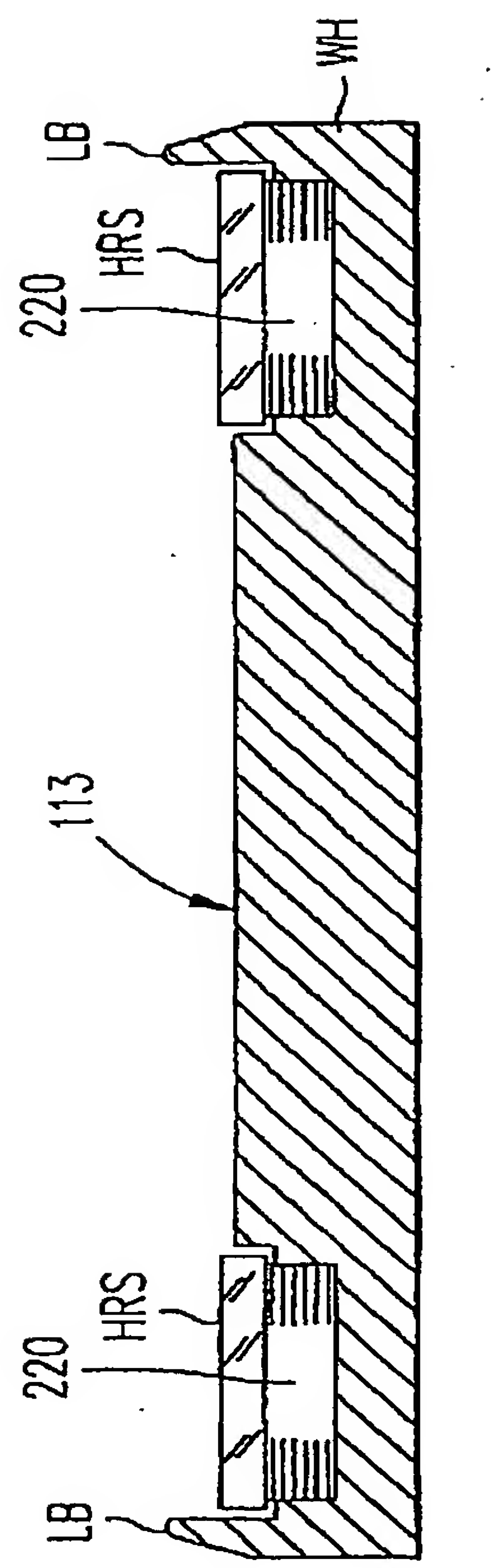
【Fig. 12】



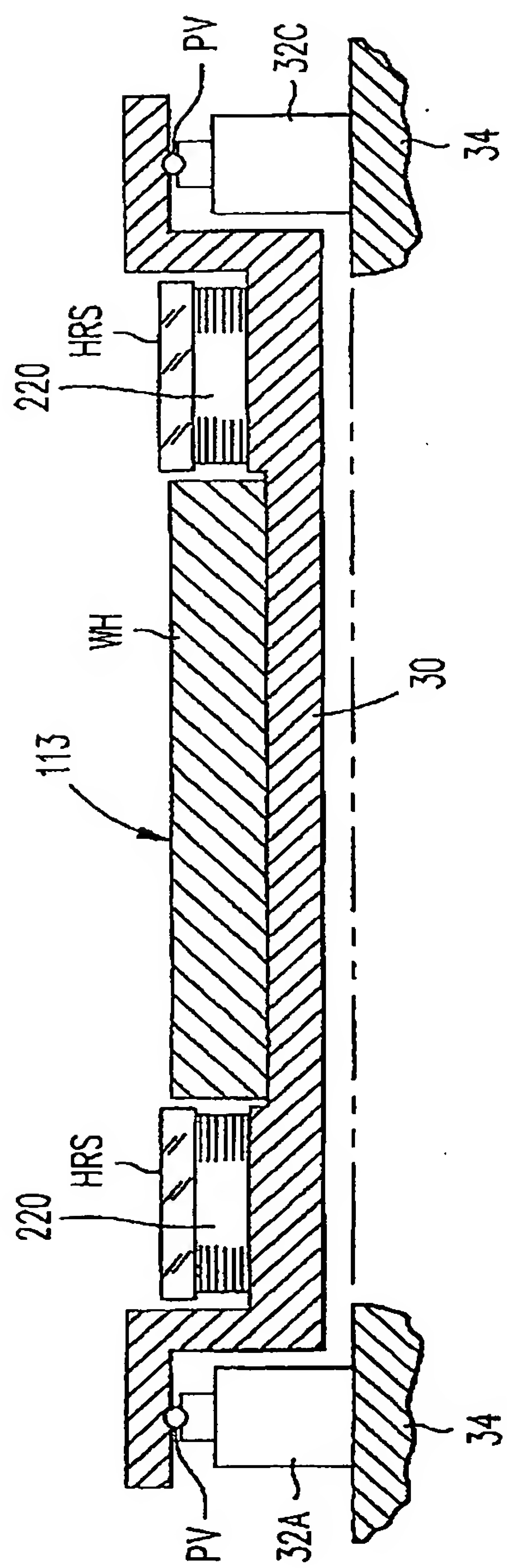
【Fig. 13】


PL
213
211
200b
200d
200
200c
215
207
205
203
202
LK
209
200a
LQ
W
WH
113

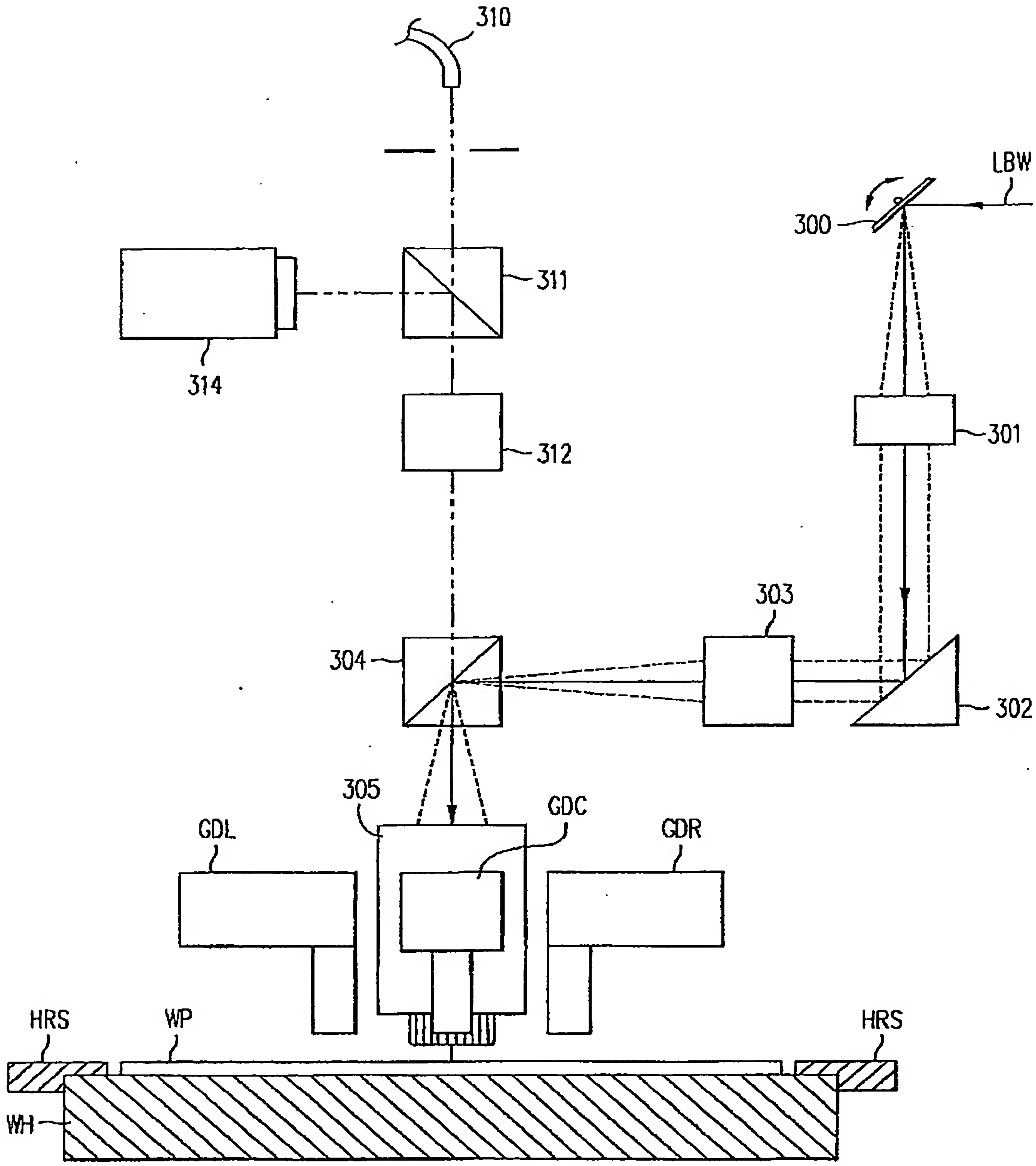
【Fig. 14】



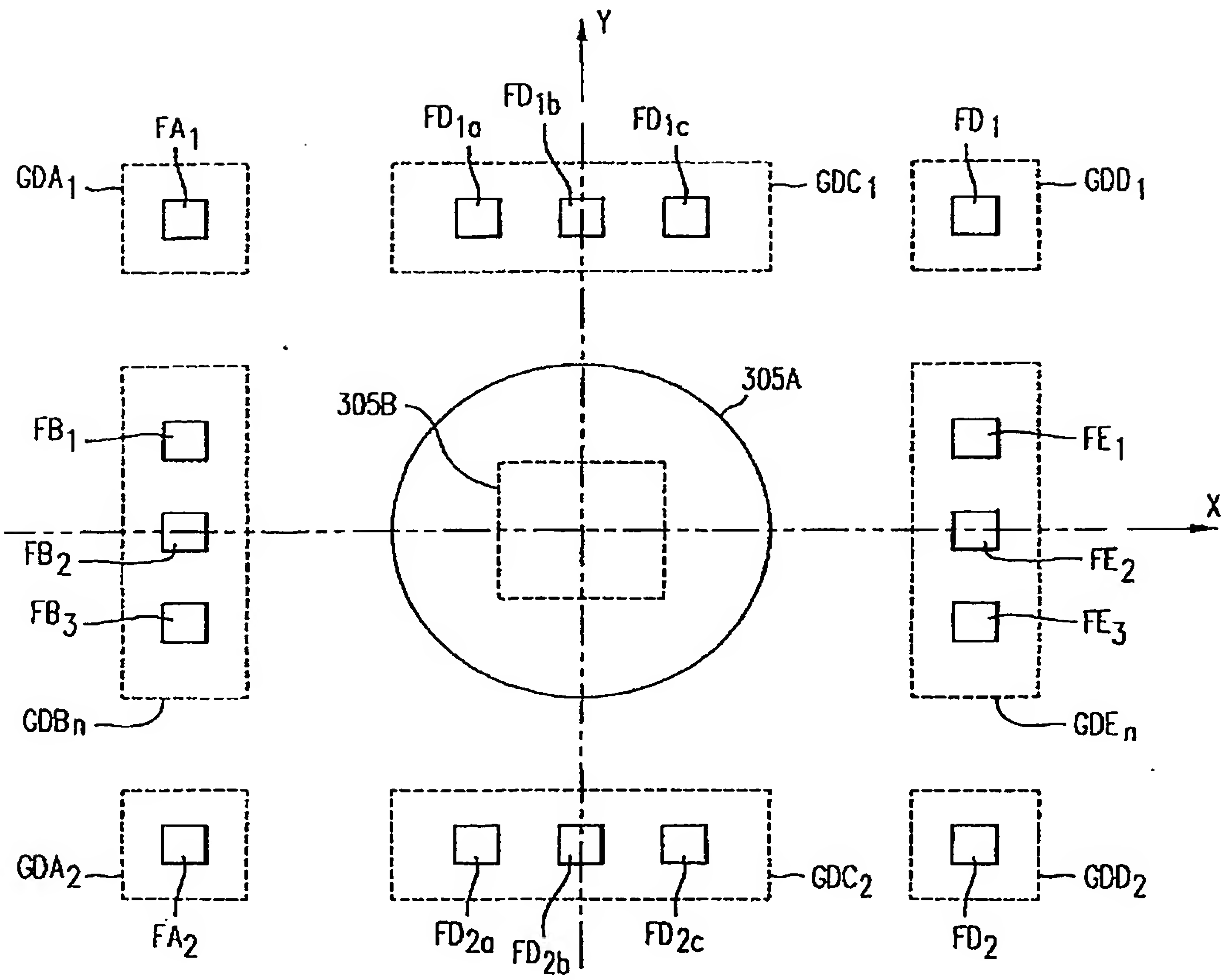
【Fig. 15】



【Fig. 16】

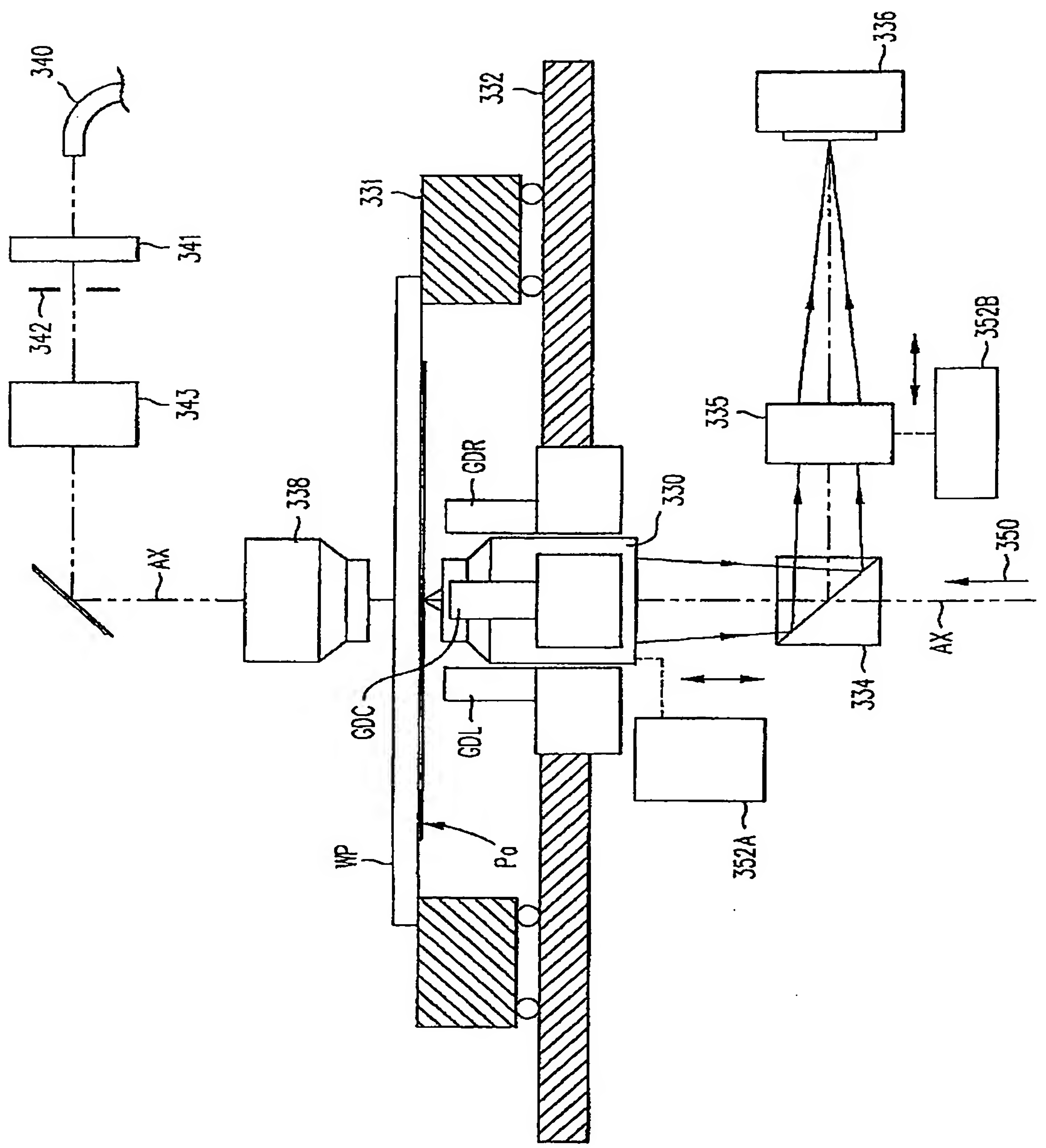

310
LBW
300
311
314
312
301
303
304
302
305
GDC
GDL
GDR
HRS
WP
HRS
WH

【Fig. 17】



Y
FA1
FD1a
FD1b
FD1c
FD1
GDA1
GDC1
GDD1
305B
305A
FB1
FE1
X
FB2
FE2
FB3
FE3
GDBn
GDEn
GDA2
GDC2
GDD2
FA2
FD2a
FD2b
FD2c
FD2

【Fig. 18】



340
341
342
343
338
AX
331
332
336
352B
335
330
GDR
GDC
GDL
WP
Pa
352A
334
350
AX